MULTI CHANNEL RADIO CONTROL

Multi Channel Radio Control

MAP TECHNICAL PUBLICATION

MULTI CHANNEL RADIO CONTROL

Multi channel control is probably what most radio control enthusiasts seek, eventually to achieve. But all too often, introduction to this more advanced stage of the radio control hobby is fraught with problems brought about by sheer lack of knowledge of the subject. It is for this reason, to help the beginner over his problems, that MULTI CHANNEL RADIO CONTROL has been introduced.

Here the beginner will find explained in simple terms the working of multi channel equipment which so often is a mental barrier and can itself lead to dismal failure.

Today, people are regularly entering the radio control hobby without previous modelling experience. Some years ago, these newcomers would have begun their radio control career with single channel equipment, but today it is not at all uncommon for a newcomer to begin radio control activities with multi channel equipment. For these people especially, there are no short cuts to multi channel success, and for these or, any beginner, MULTI CHANNEL RADIO CONTROL is an indispensable reference work.

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MULTI CHANNEL RADIO CONTROL

R. H. Warring

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Cover Plate

A multi channel model to be proud of. Dennis Bryant displays his 60 in. span Miles Sparrowhawk, which took 2nd place in the scale event at the 1964 British National Championships, powered by a Merco 49 motor and equipped with F. & M. 10 channel radio equipment.

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INTRODUCTION

Most modellers, through sheer necessity, start with single-channel radio control because it is so much less expensive than 'multi'. However, there is really no comparison in values. Multi-channel control offers so much more, especially for aircraft, that it is an *essential* choice for the serious modeller. It *is* expensive—probably more so than the average modeller can afford—but it offers so much more in control and scope. Until anyone has flown 'multi', in fact, they have not really started to experience what proper radio control is; and how consistently reliable radio control flying can be with good equipment.

There are no short cuts to success—or cost. For complete control of an aircraft you need at least eight-channel equipment, and preferably an extra two channels for elevator trim. That is going to mean an investment of around £60 to £100 or more for first class equipment. It is a lot of money to pay for a hobby interest, but it will be worth it in the long run if you are a serious aeromodeller. It is rather like the difference between owning a bicycle and owning a car—and there is just about the same difference in performance between single-channel and 'multi'.

Many people graduate into 'multi' from single-channel flying, but this is not necessary. The complete beginner can start with 'multi' and make a success of it. In fact, he would be better off learning to operate radio controlled models this way. All the practical guidance needed to understand and apply 'multi' is given in this book. The rest is mainly a matter of practice and experience which can only be gained by using radio control equipment.

Ron Warring

Every year some 100 regattas take place in Great Britain, attracting many competitors, who provide some thrilling entertainment for spectators. Here a high speed racing model is released at tick-over speed, before the operator begins his speed course.

CONTENTS

MULTI CHANNEL SYSTEMS

CHAPTER 1

The remote control of model aircraft by radio link dates back to the mid 1930s when the first serious attempts to develop working equipment were made in the United States. A radio control event was introduced for the first time in the 1936 American Nationals, since when it has remained an annual affair (with the exception of a break during the war years). Little or no development took place in this country until the immediate post-war years, but by 1946 the first British-made equipment was put on the market and by 1949 radio control was introduced as a standard event in the British Nationals.

The earliest equipment was based on single channel signalling but extracting various separate duties or services at the receiver end by means of ingenious designs of actuators. That is to say the basic signal available was, simply, 'on–off' switching, but by adapting this to operate a variety of movements in sequence in the actuator, more than one control could be operated. This is still the basis of simple single channel radio control, using compound actuators.

There is, however, a definite limit to the amount of 'compounding' or sequence operation which it is practical to utilise, especially with model aircraft. Basically, in fact, simple single channel signalling is difficult to operate as a positive and continuous method of control applied to more than one control (usually rudder), plus one other essentially non-critical control (usually engine speed). Even this has limitations, for any particular control can only be signalled in sequence. To repeat a specific control signal the complete cycle of control signals must be signalled through, however briefly.

Multi-channel radio control overcomes this inherent limitation by providing *direct* signalling of a particular control. For example, in the case of a rudder control, a multi-channel transmitter-receiver combination provides a means of directly signalling *either* right *or* left rudder, simply by movement of a switch in the appropriate directions. With single-channel signalling, even using a selective type actuator which 'analyses' the control signals, only one control position can be selected directly. The other must be selected indirectly by skipping the actuator through a complete cycle. Multi-channel signalling, therefore, is both more direct and faster than the single-channel system, which means that control is more positive.

A little thought will show that any attempt to 'compound' a multi-channel signal will result in a loss of its advantages. Thus to take full advantage of multi-channel control a separate channel is required for each and every control movement required. Thus rudder control requires two channels; elevator control would require two additional channels; aileron control a further two channels; and so on.

This raises another extremely significant point. For *complete* control of a model aircraft control is wanted on rudder, ailerons, elevators and motor speed. Thus this demands 8-channel equipment. Anything less than this gives less than complete and positive control. In fact it is desirable to go to two extra channels for a separate trim control. The equipment is, therefore, considerably more elaborate, and expensive, than single-channel radio for each control operated requires its own separate actuator as well as a more complicated receiver design to separate the individual control signals.

However, *complete* control means that the model can be flown *under control all the time*, opening up far greater scope in both model design and performance. Single-channel control relies on the model design being basically stable in flight so that it will return to its normal flying attitude after being displaced by a control movement. Thus, models which are not stable enough for successful single-channel control, such as low-wing scale models, can be flown successfully with multi-channel control. Also, models can be specifically designed for a highly aerobatic performance using multi-channel control, when they would be quite unsuited for single-channel control because of their lack of inherent stability. On the other hand models designed for single-channel control can be flown even more easily and better with multi-channel controls, although they may lack some of the manoeuvrability of the specialised 'multi' designs.

Multi-channel radio, in other words, offers far more scope than any single-channel system. It also enables models to be flown successfully, and safely, under conditions which are 'impossible' for single-channel flying. It is the *only* method for the serious radio control modeller, particularly as the best commercial equipment of this type has been developed to a high degree of perfection and is virtually trouble-free in operation.

Its chief drawback is that multi-channel equipment is much more expensive than single-channel control systems, with cost increasing proportionately with the number of channels. £50 to £100 represents a typical cost for a 10-channel transmitter-receiver combination, to which must be added the cost of actuators (one per control to be operated) which may be from £4 to £10 each, depending on the type of receiver used. Some saving is possible building the transmitter and receiver from kits, but the overall cost will still be very much higher than single-channel. For the scope it offers, and the realisation of proper radio control rather than a compromise, the difference in cost is more than worth it. There is also the possibility of spreading the cost by building up from 2- to 4-channels, and so on. Even 2-channel equipment, operating only a rudder control, will be found much more satisfactory to operate than a normal single-channel system.

The basic working of multi-channel radio is normally dependent on tone signalling. A simple transmitter radiates a carrier wave of pre-determined frequency on being switched on, which wave or signal is capable of being detected by a suitable receiver tuned to the same frequency. There are certain advantages, even for single-channel signalling, in superimposing a lower frequency signal or 'tone' on the carrier wave so that the transmitter

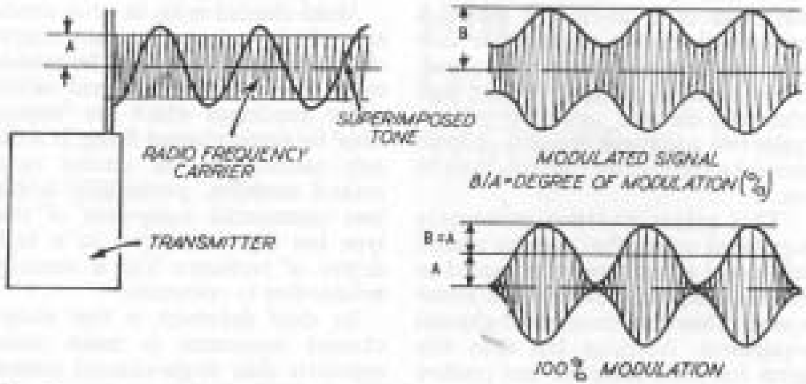
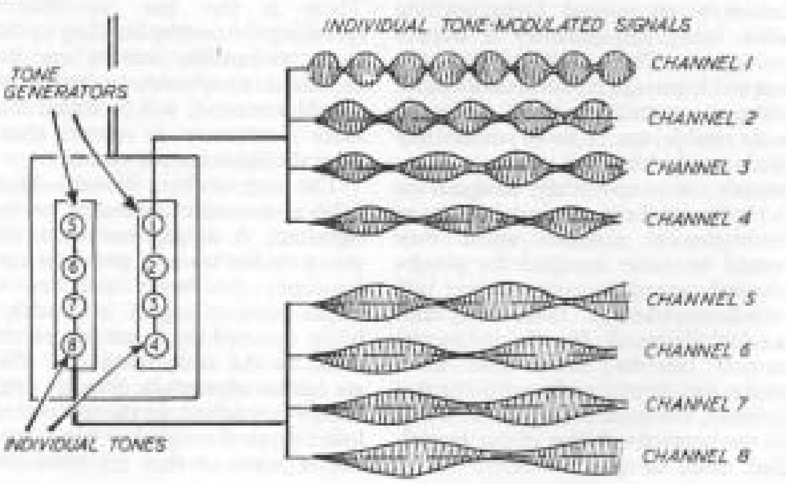


Fig. 1

output is in the form of a modulated carrier wave—Fig. 1. Most model radio control tone transmitters aim at achieving 100% modulation.

The possibility now arises of superimposing different 'tone' signals on the basic carrier, each separately selected by a control switch. Each tone will modulate the carrier in a different manner, so that each tone becomes in effect a separate signal although still transmitted at the same frequency (i.e. the carrier frequency). This is virtually the same principle as normal domestic radio broadcasting where the receiver is tuned in to the station (carrier) frequency and accepts and extracts the individual tones from the tone-modulated signal to put out as speech or music through the loudspeaker.

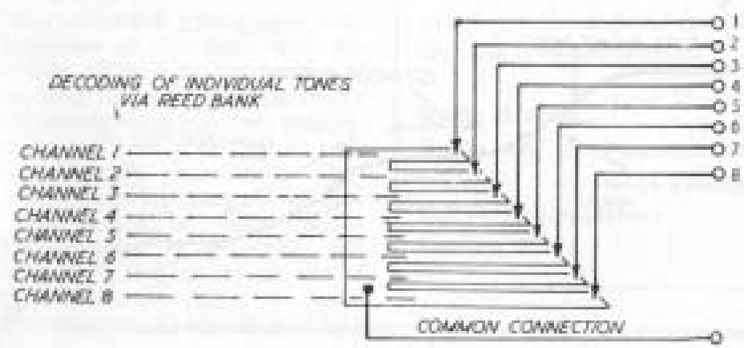
Fig. 2



For control signalling purposes, the circuitry can be simplified since it only becomes necessary for the receiver to extract a limited number of individual tones (one tone corresponding to one channel) and produce a switching response for each tone. The signalling of a particular tone (superimposed on the carrier to modulate the transmitter signal in a manner peculiar to that tone) must result in an 'on' switching action in the receiver output connecting to a particular actuator. Release of signal then switches the actuator 'off'. It does not matter whether the combined signal (carrier plus tone) is switched on and off for signalling or just the tone with the carrier normally on all the time. The receiver does not respond to the carrier signal, only to the superimposing of the tone on the carrier to produce a modulated signal. Normally, too, the individual tones will be signalled at separate times, although provision may be made for simultaneous reception of more than one tone to signal and operate more than one control signal at the same time. There are, however, limitations to the degree of 'simultaneous' operation which can be achieved without running into unnecessary, or undesirable, complications in the transmitter circuitry and interaction at the receiver end. In normal practice simultaneous operation is limited to any two or two 'banks' of four or five tones, in 8- or 10-channel transmitters, respectively—see Fig. 2. Other designs, normally used with filter-type receivers, may achieve triple-simultaneous operation in three groups.

Conventional multi-channel receivers employ one of two basic methods of tone 'identification' or translations—a reed relay with individual reeds tuned to specific tones Fig. 3; or electronic filter circuits to pass a particular tone and block all others. Details of the operation of both types are given in Chapter 3. Both have an identical function in providing an 'on-off' switching action controlled by each tone. The response, as converted into mechanical energy output by the actuator to move a control is simple 'on', corresponding to movement in a particular direction;

Fig. 3



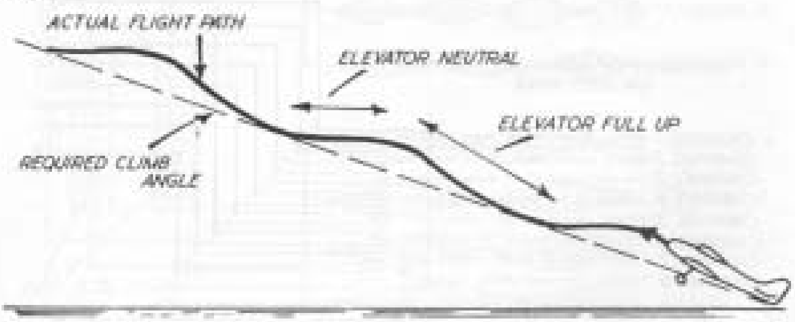
or 'off', when the actuator either returns automatically to its neutral position or stops where it is until moved by the next signal. The former (self-neutralising) action would be used on flying controls—rudder, elevator, ailerons—and the non-neutralising action on trim controls, such as elevator trim or engine throttle. A non-neutralising action is normally referred to as 'progressive' since the control moved by the actuator can be inched or 'progressed' in either direction at will using two channels (one for movement in each direction), depending on the duration of the signal.

Each actuator, or multi servo as it is usually called, is switched by two channels, one switching movement (one channel) controlling movement in one direction up to a maximum where it automatically stops; and the other channel movement in the opposite direction to its maximum. Used for control operation with self-neutralising action with no signal the control movement is either to full position and stop there with a signal held on; or neutral with no signal.

This is referred to as a 'bang-bang' control movement since the control position is either full on or neutral, depending on whether the signal is on or off. It is not possible to hold an intermediate control position, with self-neutralising action. The effect of an intermediate control position can be achieved only by 'blipping' full control on and off so that, effectively, the model is over-controlled, the control then released, and so on. This results in a 'stepped' rather than a smooth response, as shown in Fig. 4 in somewhat exaggerated form where elevator control is blipped to hold a moderate angle of climb (full elevator power would result in the model being pulled up into a loop).

Whilst this is a limitation of all 'bang-bang' controls it is not a serious one and is a small price to pay for the relative simplicity of the system whilst retaining positive self-neutralising action. With skilled 'blipping' the 'steppiness' can be reduced to a minimum, whilst trim controls enable it to be eliminated entirely on certain manoeuvres. Thus elevator trim control would enable a smooth flight path to be trimmed out for climb or inverted flight without reverting to blipping of the main elevator control. With considerable practice, 'blipping' may be done so skilfully that the control surface actually floats about some intermediate position, it not having

Fig. 4



had time to return to neutral before signalled 'on' again by the next blip, and so on. Thus a very good degree of smoothness can be achieved, although still not comparable to the standard of control possible with true proportional controls.

A 'progressive' control cannot be used for the main controls since its intermediate positions are unknown from the ground position and can only be estimated by its effect on the model. For this reason a trim control can only be used on small movements and capable of being over-ridden by a main control so that the main control can always take charge, if necessary. Despite the fact that it may appear feasible, it is *not* possible to maintain control of a model in flight with 'progressive' action on the main control surfaces, unless they can be strictly and *positively* related to a corresponding ground control movement, such as a control stick. In other words, movement of the control stick produces a corresponding positional deflection of the control surface which may be continually adjusted, as necessary, via the control stick, as in a full size aircraft. This is the basis of proportional control systems which involve a considerable greater complexity on both receiver and transmitter circuitry, and a special design of actuator to incorporate 'feed back'—see Chapter 5.

Fully successful proportional control systems of this type, with the coverage offered by conventional 'bang-bang' multi, are a comparatively recent development and cost, roughly, twice as much as a 10-channel conventional 'multi' installation. They would appear to represent the ultimate in development of model radio-control systems as providing full control with complete smoothness of operation since any degree of control displacement can be selected and held by appropriate (proportionate) movement of a control stick. They will not necessarily replace 'bang-bang' multi, however, for they need more skill and practice to master, whereas flying with 'bang-bang' multi can be learnt quite readily. Also the cost of such systems must inevitably remain higher than conventional 'multi'. Their main field of application would appear to be for competition flying, where smoothness of control is a particular asset, or for the serious radio control enthusiasts concerned with operating the most comprehensive type of control system and capable of affording the extra initial cost.

RADIO LICENCE REQUIREMENTS

A licence is required for the operation of any radio control equipment in this country, whether actually used in a model or not. This costs £1 to cover a period of five years. No technical examination is required to obtain a licence. It is only necessary to write for an application form to the G.P.O. and return this completed form. The address for licence forms (and for returning completed forms) is:

Radio Branch
Radio and Accommodations Dept.
G.P.O. Headquarters
London, E.C.1.

MULTI TRANSMITTERS

CHAPTER 2

The simplest practical form of transmitter for generating a 'carrier' wave is based around a single valve (or transistor) oscillator circuit. Such a circuit does, however, tend to be somewhat critical in operation and two stages are to be preferred—an oscillator feeding into an RF (radio frequency) amplifier and thence to the aerial. This combination, comprising a Master Oscillator and Power Amplifier is generally referred to as a MOPA type. In a valve transmitter the two valve elements (oscillator and amplifier) may be contained within a single envelope, so that physically, at least, both the MOPA and the simple oscillator transmitter may employ only one valve. The MOPA type is, however, almost invariably preferred for tone transmitters since it is much more easily modulated by the tone generated by a further valve (or transistor circuit) applied to the RF amplifier stage—Fig. 5.

The power of radio control transmitters is limited to a maximum of 1½ watts output under G.P.O. regulations. The actual efficiency of a transmitter can vary widely, depending primarily on the circuit design and may be as low as 10% although higher figures are obtainable. The most direct method of ensuring high output

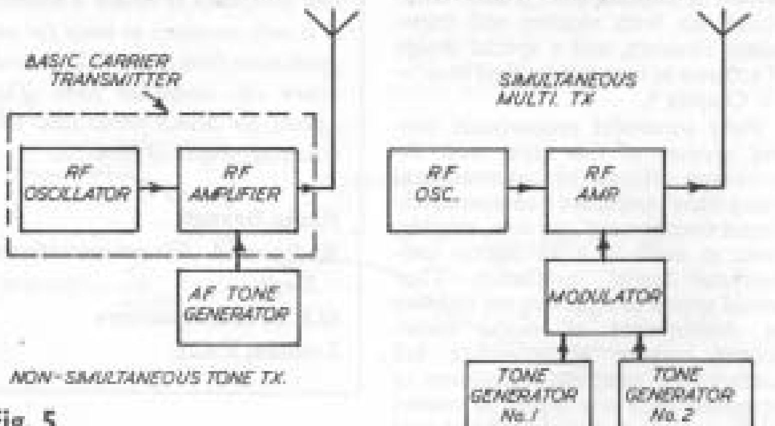


Fig. 5

The Citizenship 6 channel, all transistor transmitter, showing circuit construction on a single printed circuit baseboard. Six 'Pots' for adjusting the frequencies of the tone signals are at top of board. Note identification of control functions on transmitter front face.

power is, therefore, to use a high input power when, for example, 5 watts input should ensure an output power of at least ½ watt. However this means using a large transmitter battery or power pack with heavy current drain, which may be suitable for ground-standing transmitters but is not desirable or even practical with hand-held transmitters where battery size has to be reduced to a minimum. Thus a power input of 1 to 2 watts is more usual, or considerably less in many cases (e.g. all-transistor transmitters). The relatively low output power available then needs a really efficient aerial system, unless range is to suffer.

Aerial coupling in particular tends to become a critical feature of the aerial design, particularly as telescopic aerials (virtually standard fitting on hand-held transmitters) tend to be relatively inefficient and are invariably shorter than the 'optimum' length. A 'full wave' aerial length, for example would be about 34 *feet* long for the most efficient transmission of a 27 megacycle signal. The older type of ground-standing transmitters normally used a quarter-wave aerial (optimum length 8 ft. 7 in.). Hand-held transmitters normally employ a telescopic aerial extending to about 48 in. long, although some are shorter.

Reducing the aerial length will, normally, have the effect of reducing output signal strength and thus range. Where input power is low to start with, and thus output power proportionately very much lower still, aerial efficiency may be increased by fitting a centre loading coil to the aerial. This has the effect of increasing the 'working' length of the aerial and thus improving the overall efficiency of the transmitter to compensate for low input power. All-transistor transmitters, where input power is low to start with, commonly employ a centre loaded aerial.

Range is largely an arbitary factor since it is dependent specifically on a particular transmitter-receiver combination. This with a particular transmitter, receiver 'A' may respond satisfactorily up to a range of, say, 800 yd., and receiver 'B' only to 200 yd. The 'range' of the transmitter is the same in both cases, but the apparent range is 800 yd. with one combination and 200 yd. with the other—Fig. 6.

Range is also affected by operating conditions. With model aircraft con-

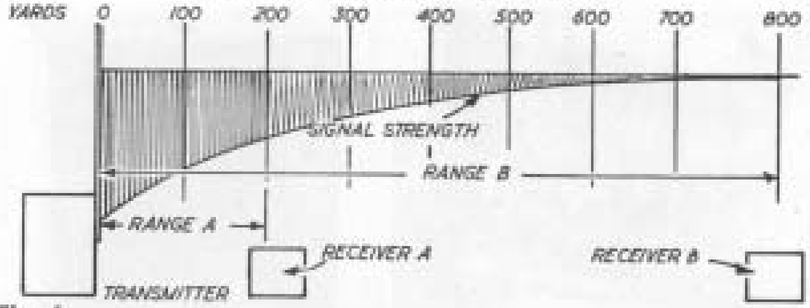


Fig. 6

trols a minimum range of 800 to 1,000 yd. is desirable. With model boat controls a range of less than 100 yd. may well suffice, depending on the size of the pond. Also effective range will be higher between a ground station (i.e. the transmitter) and a model aircraft at height than with the same combination checked out ground-to-ground. Ground-to-air range may, in fact, be anything up to three times ground-to-ground range under typical conditions.

Since actual working is affected by the receiver design, working with any given transmitter, it also follows that the *type* of receiver is likely to affect the range achieved. Receivers which work on 'tone' signals are, in general, capable of responding at lower signal strengths than receivers designed only for carrier wave reception, hence they are more suitable for use with lower powered transmitters. Equally, tone operation is more suited for lightweight transmitter designs where minimum size batteries can be used with only moderate current drains and relatively low power outputs. Superhet receivers are even better in this respect because of their extreme selectivity.

Satisfactory performance also depends on the receiver being tuned to the transmitter to receive maximum signal strength, and staying 'in tune'. With simple transmitter circuits, however, there may be a tendency for the frequency to drift, which puts the receiver out of tune with loss of signal strength and corresponding reduction in effective range.

Frequency drift can virtually be eliminated on transmitters by employing crystal control. A crystal is simply an RF component which has a natural frequency of operation. If incorporated in the oscillator circuit or output it will allow that circuit to oscillate only at a predetermined frequency, thus the signal (carrier) frequency always remains 'spot on', within the limits of the peaking characteristics of the crystal.

To control the frequency of the RF oscillator direct, the crystal must either have the required frequency of a suitable sub-harmonic (usually a third overtone or one-third of the frequency required). It can then be coupled into the circuit as shown in Fig. 7. Alternatively a sub-harmonic crystal with one-half of the required frequency may be used with 'frequency doubling' applied in the transmitter circuit. This can be done in the anode circuit of the oscillator stage and then fed to a 27 megacycle power amplifier; or the output of the oscillator stage made 27/2 – 13·5 megacycles to drive a frequency doubler in the power amplifier stage—see Fig. 7.

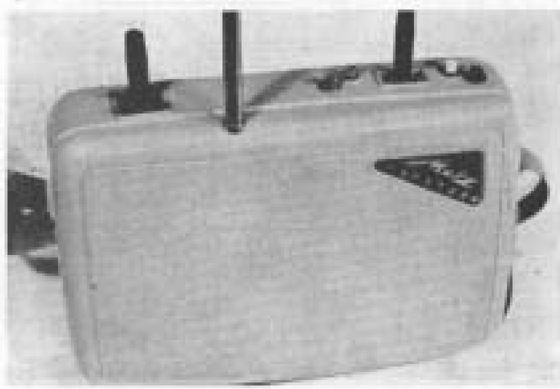
Strictly speaking, crystal control of the transmitter is not *necessary* for

satisfactory operation with super-regenerative receivers since the tuning of such receivers is invariably broad in any case. Crystal control is, however, a legal requirement of radio control transmitters in certain countries (e.g. America and Germany) to ensure that the transmitter cannot drift off the permitted operating frequency range. Because it has not been obligatory in this country British transmitters have not adopted crystal control as standard (mainly because manufacturers can produce a cheaper transmitter by eliminating this relatively expensive single component), although it is almost invariably employed with a 'multi' transmitter. When used with a superhet receiver, a crystal controlled transmitter is *essential* for satisfactory operation as tuning must be exact and *stay* exact.

The conventional multi-channel transmitter must be a 'tone' transmitter but, basically, differs from a single-channel tone transmitter in that the audio frequency (AF) circuit is designed to provide a number of different tones, any one of which can be fed into the basic circuit at will to modulate the RF signal accordingly—Fig. 8. When simultaneous operation is required, two (or more) separate tone generators are required, when a tone from each can be fed simultaneously into the basic circuit. Simultaneous operation is normally restricted to 8-, 10- or 12-channel transmitters, offering simultaneous operation on two selected 'banks' of controls via two separate tone generators.

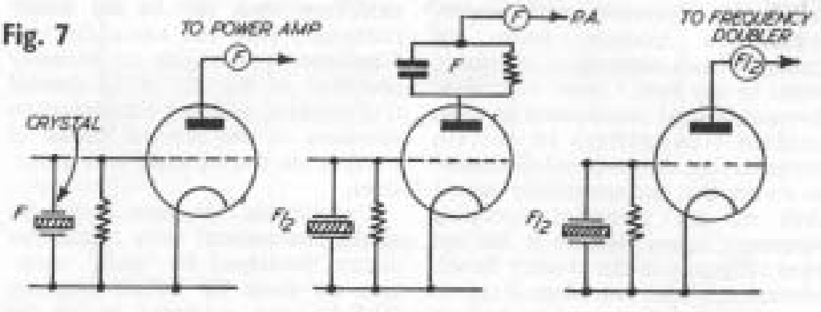
Undoubtedly the most successful of the conventional valve transmitter circuits developed for 'multi' operation are those by Robert Dunham (U.S.A.) and marketed under the name 'Orbit'. Apart from establishing an extremely high reputation for reliability from the time they first appeared they have formed the basis for comparison or development of similar circuits by other manufacturers and designers, their only practical limitation as such being a comparatively high current drain on the two 67·5 volt high tension batteries employed (135 volt h/t).

Circuits of the Orbit 4 and Orbit 10 (simultaneous) are shown in Figs. 8 and 9, respectively. The 4-channel multi transmitter circuit (Fig. 8) is virtually identical to that of a single-channel tone transmitter with the addition of four elementary 'tuned' circuits controlling the individual tones generated by the AF oscillator. Each of these 'tuned' circuits com-



Metz 10 transmitter for tuned filter system. Control column layout here provides twin 'joysticks' and four control buttons. This transmitter is triple simultaneous, permitting transmission of three signals simultaneously.

Fig. 7



F-CARRIER FREQUENCY (27MC/S)

prises a variable resistor (potentiometer) allied to a fixed capacitor, switched into the circuit by manipulation of the appropriate key (each key being linked to another switch which then applies the generated tone to the RF oscillator to produce modulation). The actual tone generated is adjustable, by means of the variable resistor, so as to match to receiver requirements. RF frequency, on the other hand, is fixed and stabilised by the crystal. The necessity for variable tuning on the tone circuits will be made clear in the following chapter dealing with receivers.

For simultaneous operation two separate tone generators are employed, each 'tunable' via three, four, five or six separate potentiometer controls. Any *one* of these four, five or six tones can be applied to modulate the RF output signal simultaneously with any *one* tone from the second AF oscillator. Thus the circuit provides double-simultaneous operation, if required.

Simultaneous operation is not necessary with up to four channels, hence a simpler circuit can be employed. Six channel non-simultaneous operation could be incorporated on a similar circuit merely by the addition of two

ORBIT 4 CHANNEL TRANSMITTER

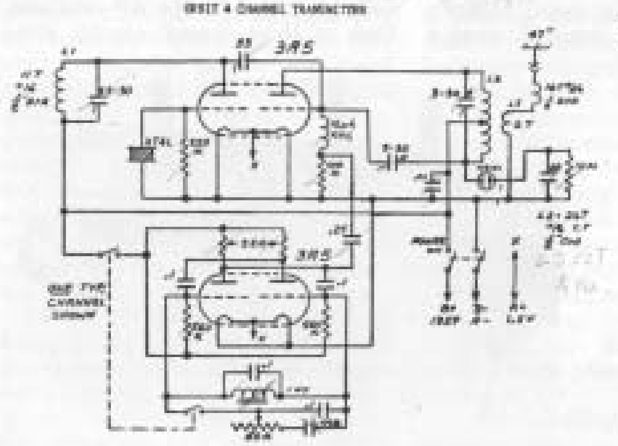


Fig. 8

ORBIT 10 CHANNEL SIMULTANEOUS TONE TRANSMITTER

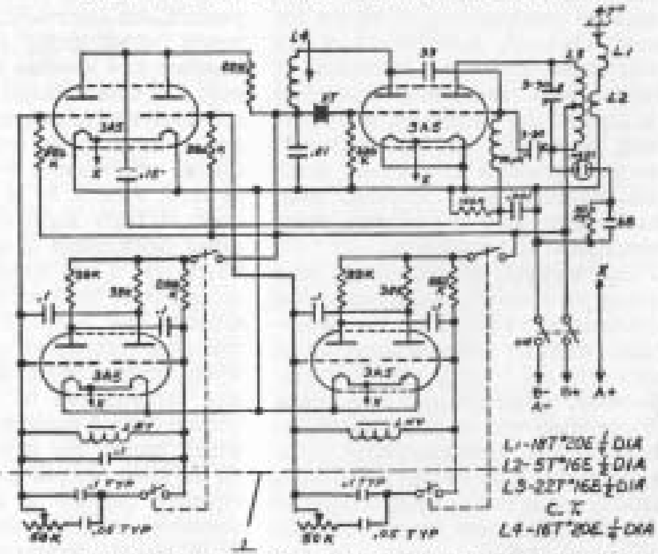
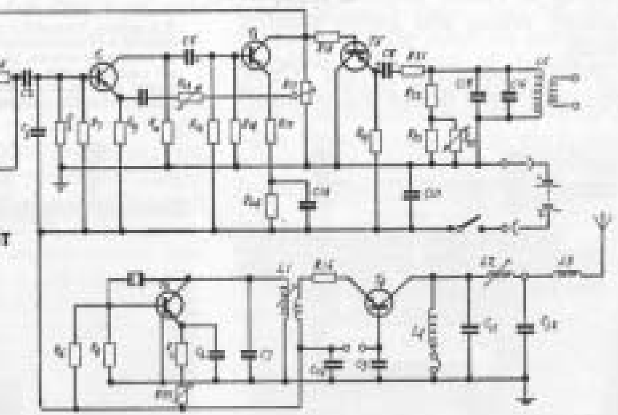


Fig. 9

ADD COMMANDS BELOW DASH LINE FOR NUMBER OF CHANNELS

Fig. 10



GRUNDIG TX CIRCUIT

R1—3.3k
R2—3k
R3—3k
R4—3.3k
R5—20k
R6—910 ohms
R7—5.6k
R8—10k
R9—1.1k
R10—3k
R11—30 ohms
R12—910 ohms
R14—11k
R15—11 ohms
R16—4.7 ohms
R17—2k
R18—10k
R19—3.3k
R20—1.3k
R21—470 ohms
R22—2k
R23—2k

R24—200 ohms
R25—300 ohms
C1—5n
C2—47n
C3—33n
C4—5n
C5—5n
C6—4.7n
C7—50n

C8—5n
C9—4.7p
C10—100n
C11—68p
C12—160p
C13—4.7n
C14—5n
C15—0.1n
L1—HFBU 9290-035

L2—HFBV 9290-036
L3—HFBV 9290-037
L4—HFBV 9290-038
L5—HFBV 9290-044
T1—AC126
T2—AF118
T3—AC126
T4—AFY19
T5—AC128

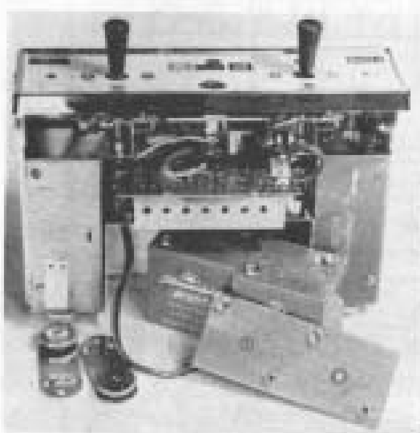
more 'tone tuning' potentiometer-capacitor combinations. With six (or more) channels, however, there are both circuit advantages in separating the individual tones into banks applied via separate AF oscillators, and operating advantages in having simultaneous operation of controls available. At this stage, therefore, multi transmitters tend to become more complicated and expensive.

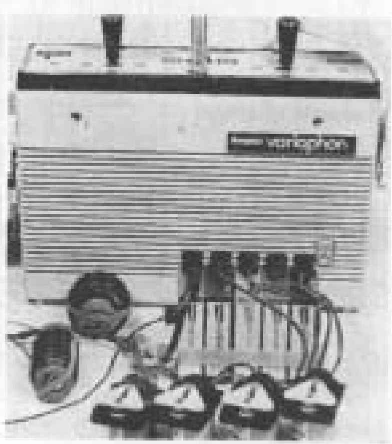
The method of individual 'tone tuning' via a variable resistor-capacitor combination switched by the appropriate 'tone' key is almost universal on conventional 'multi' transmitters. However, purely resistive tone tuning can be used and is a feature of the British (1964) Remcon design. This is claimed to have certain advantages, notably in the simplicity of arriving at suitable component values for the individual 'tuned' circuits. In this particular case, however, the Remcon is designed primarily for home construction from kits. On a commercial production basis there is virtually nothing to choose between resistive-capacity tuning and purely resistive tuning.

Valve transmitters of the 'Orbit' type, with good design and construction, and proper selection of components, are extremely reliable with a power output giving adequate range matched to a suitable receiver. Their only real disadvantages are that they are comparatively heavy and bulky for a hand held instrument (e.g. typical weight about 5–6 lb. and size 9½ in. × 7 in. × 3½ in.); and current drain is fairly high, calling for frequent replacement of quite expensive batteries. Thus although reliable enough there has been a marked trend towards the adoption of the all-transistor transmitter as a 'standard', where smaller, lighter and less expensive batteries can be employed and current drain is reduced to proportions where battery life is extremely long. At the same time, of course, transistor circuitry permits a more compact assembly, reducing weight to about 2¾ lb. and size to about 8 in. × 6½ in. × 2½ in.

An important feature with all-transistor transmitters is the stability of the circuit over the full range of

Grundig 8 transmitter for the Grundig tuned filter R/C system. Transmitter may be purchased as a four channel unit and subsequently changed to 8 channel by additional add-on, plug-in circuitry. A ten channel unit is similar, with the addition of two push-button controls. Note re-chargeable power pack for this all transistor transmitter.



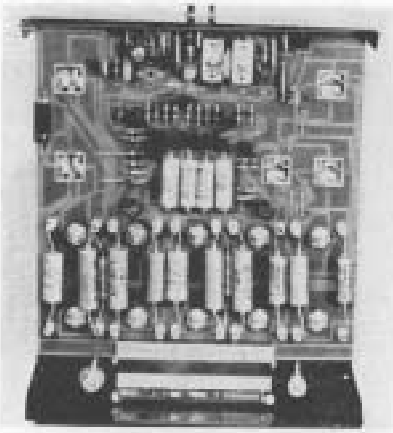


In the interests of economy, some modellers prefer to build their own equipment. Where multi channel equipment is concerned, this is no mean task and requires technical skill unless the job can be simplified as is the case with this Remcon 12 channel transistor transmitter, supplied in kit form with selected components. Total cost is in the region of £18.

likely operating conditions. Transistors are heat-sensitive devices, affected by changes in ambient temperature and by heating effects of the current passed through them. It is therefore necessary to make provision in the design of the circuit to stabilise the working characteristics of the transistors over a normal ambient temperature range of about 20°F to about 120°F. It is possible that the latter temperature may be exceeded inside the case of the transmitter exposed to hot sunlight and the stability and performance of some all-transistor transmitters may be effected by extremes of temperature. Most modern circuits are suitably temperature-compensated, but the fact remains that continual exposure to direct heat of the sun on a very hot day should always be avoided with any electronic apparatus incorporating transistors.

The proportionately lower output power normally realised with all-transistor transmitters may or may not be compensated for by using a centre loaded aerial. On typical 'British' and 'American' all-transistor 'multi' transmitters a centre loaded aerial has become virtually a standard. On Continental transmitters this has not been so, but the latter are usually designed to operate with a different type of receiver, e.g. tuned filter circuits instead of a reed relay, which require less receiver 'power'. Thus the receiver can operate successfully on weaker signal strengths. A superhet receiver will also operate on lower signal strengths. Thus with reed receivers used with all-transistor transmitters, a superhet will normally give better range than a super-regen receiver, although range may be quite adequate with the latter for successful operation. The type of transmitter used is identical in both cases—i.e. the same transmitter can operate either a super-regen or superhet receiver, only in the latter case the 'spot' frequency, as determined by the crystal must agree with the crystal value used in a matching superhet receiver. In practice, this means that transmitter and superhet receiver are specifically related by means of a matched pair of crystals, the transmitter crystal corresponding to one of the selected spot frequencies for superhet operation and the receiver crystal frequency differing (normally lower in frequency) by the IF of the superhet circuit—see also Chapter 3.

The majority of conventional 'multi' transmitters follow a more or less

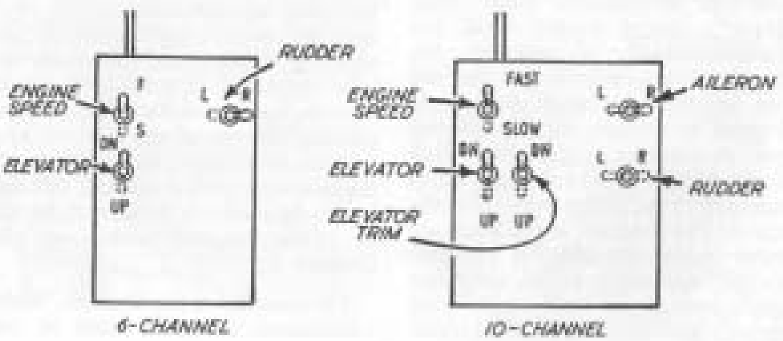


Orbit 10 channel transistor transmitter showing circuit construction. Tone 'pots' are on lower half on circuit board, with re-chargeable power pack in base of case. Front face of case displays layout of controls with charger inserted in charging socket. Note centre loaded aerial.

standard layout of the controls, the various tones being 'keyed' by operation of a two position self-centring on release lever switch, with the direction of movement consistent with a natural direction—e.g. side to side for rudder control, up and down for elevators, etc. The control switches are also positioned for easy and natural operation by the thumbs of each hand, both hands at the same time grasping the transmitter case. Rudder and aileron controls are then normally operated by the right hand (thumb); and elevator, engine speed and elevator trim by the left hand (thumb)—see Fig. 11.

This arrangement is by no means fixed, however, although the actual *position* of individual switches is usually similar on different makes of transmitters. A nominally allocated switch can readily be made to operate a different service, simply by tuning the corresponding potentiometer control to operate a different pair of reeds,

Fig. 11



or merely allocating the reeds to control different services—see Chapter 8. The latter method would be more usual, if a change is required, since the tuning range of the individual potentiometers is usually limited.

It is, however, important that once having adopted a particular allocation of control switches this should be adhered to if the transmitter is used with another receiver; or another transmitter is employed. Manipulation of the right switches becomes instinctive with practice and if the duty allocation is altered, a certain amount of 're-learning' is needed, otherwise one is likely to select the wrong control during a moment of automatic reaction.

On other types of multi transmitters pairs of two-position switches may be replaced by a four-position self-centring on release switch. This then becomes, in effect, a miniature control column with a natural and logical allocation of duties. With more than four channels two such four-position switches may be employed; or just one four-position switch or control column for rudder (or ailerons) and elevator and the other services selected or operated by two-position of one-way switches (such as a pushbutton), as appropriate.

All control switches represent a vital part of the functioning of the transmitter and need periodic inspection to ensure that contacts are clean and undamaged and that the switch action remains smooth and easy. Some switches are very much better than others in this respect, with a positive movement easily applied and felt and a reasonably strong and equally positive return to neutral when pressure is released. A switch with a dubious or awkward action, or one which is too light, can make for difficulty in control and is best replaced.

The on-off switch is also deserving of mention. This normally switches on the carrier and is left 'on' all the time the transmitter is to be operated. The switch is usually of the toggle type, but may be a slide switch on some transmitters. If a toggle switch, it is best to arrange that 'on' is up rather than down, as in this position it is least likely to be accidentally knocked off during handling of the transmitter. 'Up' for 'on' is standard practice with American transmitter switches, but the reverse fitting is usually adopted in this country. Altering the switch is usually quite straightforward—merely loosening its fastening ring, turning through 180 degrees and retightening in position.

RADIO CONTROL FREQUENCIES

Permitted frequencies for the operation of radio-control equipment in this country covers the band 26·96 megacycles/second to 27·28 megacycles/second (11·12 to 11·1 metres wavelength). Crystal control of transmitters is not obligatory in Great Britain but is in many other countries (e.g. the United States and Germany).

The 464–465 megacycles/second band is also available for radio control use in this country but can be ignored as far as the average modeller is concerned. No commercial equipment is produced for this frequency. Other frequencies used are 50–54 megacycles/second (in America only), and 40–41 megacycles/second (in Germany). It is not legal to operate such equipment in this country unless modified to operate within the 26·96 to 27·28 megacycles/second band.

MULTI RECEIVERS

CHAPTER 3

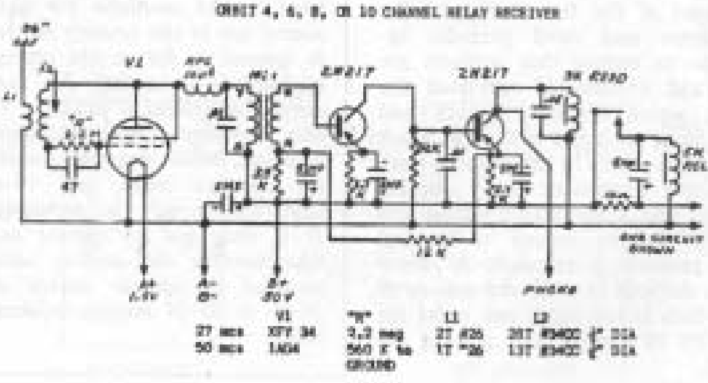
The basic function of any radio receiver is to be responsive to RF signals received at a particular frequency whilst rejecting spurious signals. The balance of the receiver circuit is then concerned with decoding the signal received and translating it in terms of useful, or useable, output.

The ability of the receiver to pick up signals is determined by its *sensitivity*. The weaker a signal the more sensitive the receiver must be to pick up it and produce a satisfactory response in the receiver circuit. Sensitivity, therefore, largely governs the range of a particular receiver used with a particular transmitter.

At the same time the receiver must be *selective*, i.e. capable of being tuned to respond only to a particular transmitted RF signal. If the tuning is too broad, the receiver will lack selectivity and will pick up other RF signals adjacent to the specified transmitted frequency it is intended to detect and respond to them as well as the correct signal.

The conventional radio control receiver normally employs a super-regenerative circuit which has the

Fig. 12



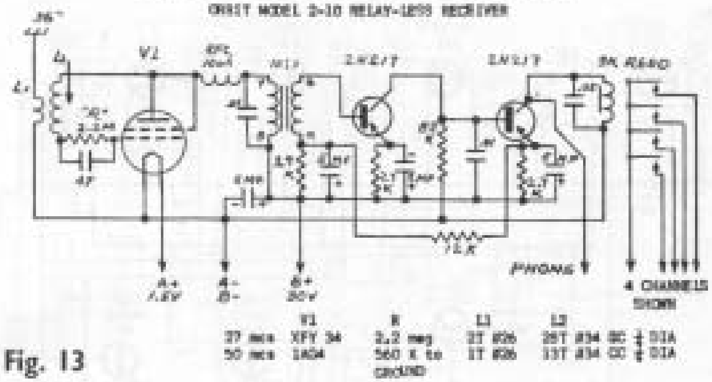
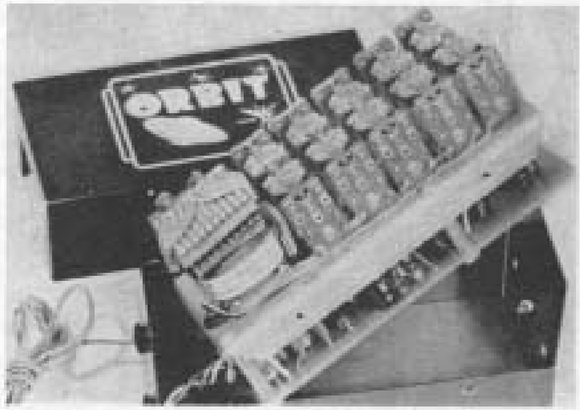


Fig. 13

advantage of providing good sensitivity in a simple manner. On the other hand too great a sensitivity is not desirable since this means that the receiver will pick up other weak signals as 'interference'. Carried to the limit, extreme sensitivity may mean critical stability, where the receiver is working on the point of skipping in and out of oscillation. The circuit designer must, therefore, produce a suitable compromise as regards the degree of sensitivity that can be tolerated, or make provision to adjust sensitivity separate to normal tuning to meet particular operating circumstances.

The super-regen receiver is normally quite 'broad' in tuning. In other words, it has inherently low *selectivity* and even when tuned accurately to a particular frequency may well be responsive to other signals at different frequencies. For example, if tuned to, say, 27 megacycles exactly, it may well pick up signals at, say 26 megacycles and 28 megacycles with sufficient strength as to respond to them. For this reason it is normally impossible to operate two super-regen receivers at the same time although each may be



Orbit 10 relay super-regenerative receiver showing twin deck construction with reed bank and ten relays on upper deck. Receiver circuit is on lower deck.

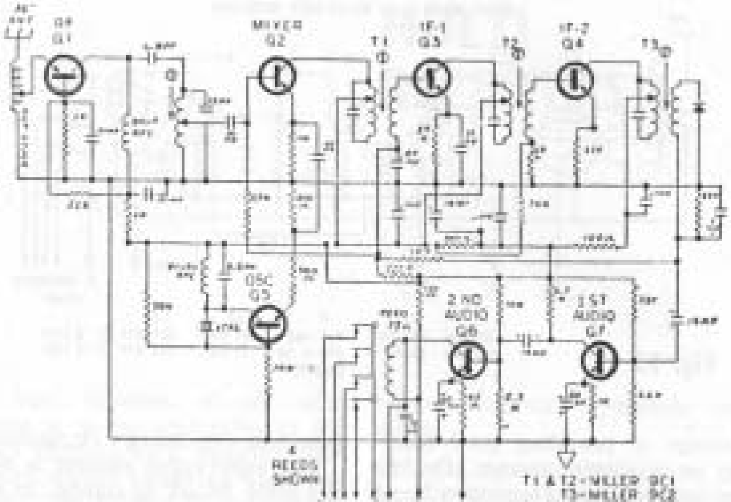


Fig. 14—Orbit Superhet Rx.

controlled by separate transmitters operating at different frequencies. The permitted band width for radio control operation—26·96 to 27·28 megacycles/second—is too narrow to provide 'separation' of the broad limits of acceptance of the super-regen circuit. At the same time, of course, a super-regen receiver is particularly prone to interference from any source of RF at around 27 megacycles which may be present with sufficient field strength where the receiver is being operated. This problem of 'interference' becomes more acute with increasing receiver sensitivity.

Despite this limitation, the super-regen receiver has remained the standard type for both single- and multi-channel work, mainly on the score of relative simplicity (leading to minimum size), lowest cost and the

Citizenship six channel reed superhet receiver, showing reed bank and receiver circuit on a single baseboard.

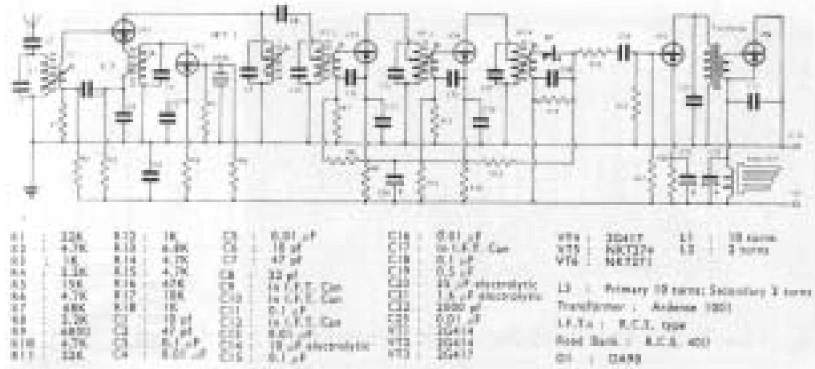
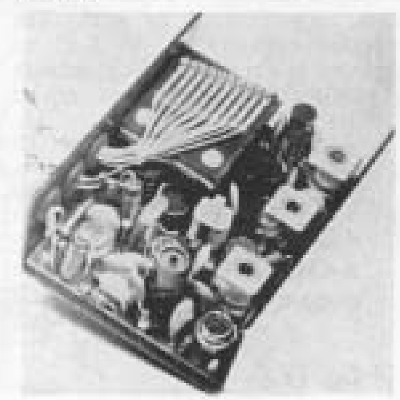


Fig. 15—R.C.S. Competition 10 Superhet Rx. for Reeds.

fact that it is readily tunable to any suitable transmitter. The superheterodyne (superhet) receiver, on the other hand, is the only type capable of providing interference free operation, but is inevitably bulkier, heavier and considerably more costly.

Whilst the super-regen receiver works on the principle of detecting the incoming radio signal at radio frequency, the superhet 'mixes' the incoming signal with a fixed frequency signal generated by the receiver itself and detects only the resulting beat or true difference frequency (usually of the order of 450 to 475 kilocycles/second). As a result the circuit is extremely selective—so selective, in fact, that up to six or even more transmitter-receiver combinations may be worked simultaneously within the 26·96 to 27·28 megacycle band at different 'spot' frequencies without any interference between them (see Table I). In practice, the superhet receiver does not result in absolute freedom from interference, but virtually so under normal operating conditions.

From the circuit designer's point of view the superhet requires careful planning in order to achieve maximum stability as the receiver is 'untunable' by simple means. That is to say, the circuit must be stable enough for it to require no tuning for long periods after being initially set up as completely satisfactory tuning can only be achieved with the aid of an oscilloscope and is thus outside the capabilities of the average user. Crystal control is necessary to match the receiver to the transmitter (i.e. employing a matched pair of crystals, one in each unit); and full temperature compensation in the case of transistor circuits.



Orbit relayless, 10 channel reed superhet receiver, showing tightly clustered components on single baseboard with 10 channel reed bank. Compactness of relayless receivers makes installation easier.

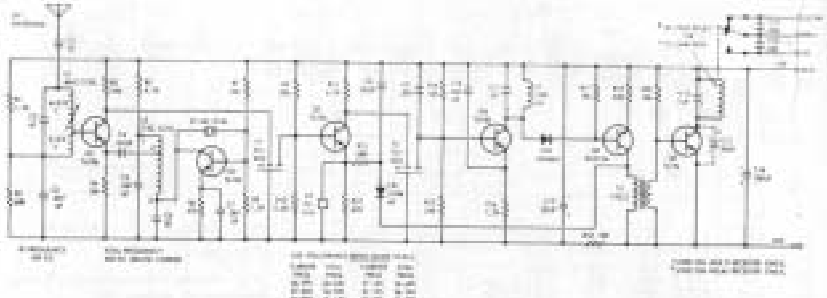


Fig. 16—C & S Cardinal Rx. with 'transfilter' I.F. Stages.

Superhet receivers, being a later development, normally employ all-transistor circuits. A valve detector followed by transistor-amplifier stages may still be used on super-regen receivers, although again virtually all modern designs favour all-transistor circuitry. The advantages are similar to those with transmitters—reduced bulk and weight and the use of smaller, low voltage batteries with low current drain. Thus whilst a typical valve-transistor receiver may require one 22½ or 30 volt high tension battery plus a 1·5 volt low tension battery, the equivalent all-transistor circuit operates off a single battery of 4·5 to 9 volts (6 volts being a typical average for 'multi' receivers).

Output function of a receiver is the same, regardless of its type. The superhet receiver can, in fact, be regarded as a super-regen circuit with a special 'front end', plus crystal control to ensure complete freedom from drift. The balance of the receiver circuit is then concerned with decoding the individual tones—i.e. extracting the AF component from the modulated RF signal received in terms of some form of useable output.

There are two basic forms of decoding possible—electronic, or electro-mechanical filtering. The former appears the most direct and logical at first sight, but is not the most popular method. It is, however, favoured by Continental radio control designers who have virtually standardised on this method for modern production designs. American multi-channel receivers, and British, have almost always preferred the use of the reed-relay for 'mechanical' separation of individual tones.

Electronic filtering, being the simplest in principle, will be described first. Here the detected and amplified signal developed in the receiver is passed to a number of paralleled filter components, one filter circuit for each tone. Each filter is designed to pass only a particular AF 'tone' and block or stop all other frequencies. The same principle applies whether the original signal is demodulated first or not. Filter A will pass only tone signal A, filter B passes only tone signal B, and so on—Fig. 17. The output from each filter is then fed to individual relays, one per filter.

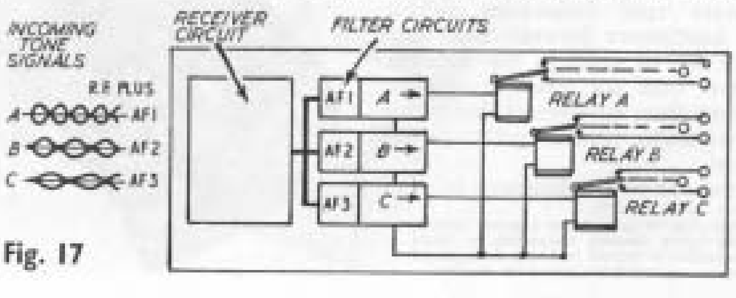
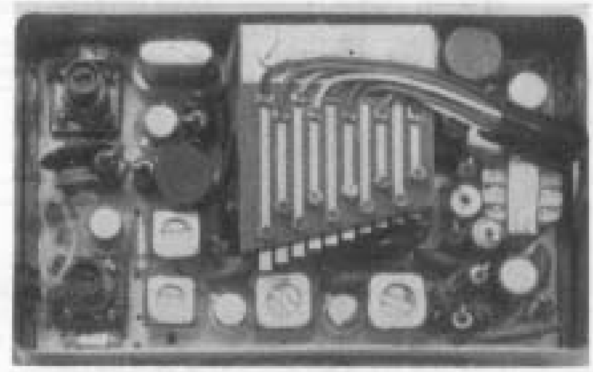


Fig. 17



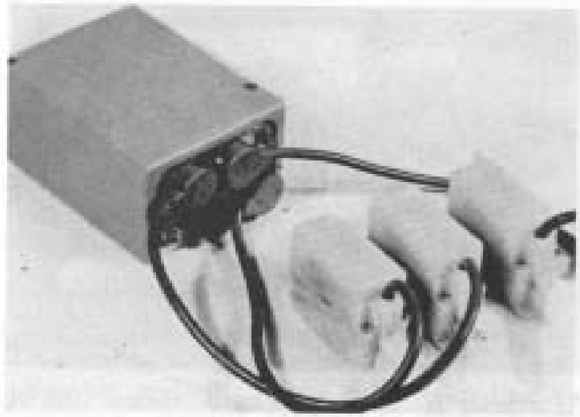
Radio Control Specialists' Competition 10 superhet receiver, showing layout, with four I.F. cans, and reed bank. Note staggered reed contacts.

The response of the receiver is then perfectly straightforward. The reception of tone A results in filter A passing that tone, with sufficient current rise to operate relay A. Similarly, tone B operates relay B, tone C operates relay C, and so on. The relay contacts are merely used as switches controlling the 'on–off' condition of the separate servo circuits wired to them.

An outstanding example of this type of multi receiver is the (German) Grundig. Here the receiver is a separate unit, onto which are plugged separate filter units. Each filter unit comprises two filter circuits and two relays to build up a 2-, 4-, 6- or 8-channel 'multi' receiver by plugging on one, two, three or four filter units (each unit comprising, of course, a pair of different tone filters).

The chief limitation of tone filters,

Grundig 8, tuned filter receiver showing 'modular' construction. Receiver is in separate box and plugs into four, twin channel filter modules all of which plug together. Servos also plug into filter units, eliminating soldering work by the operator.



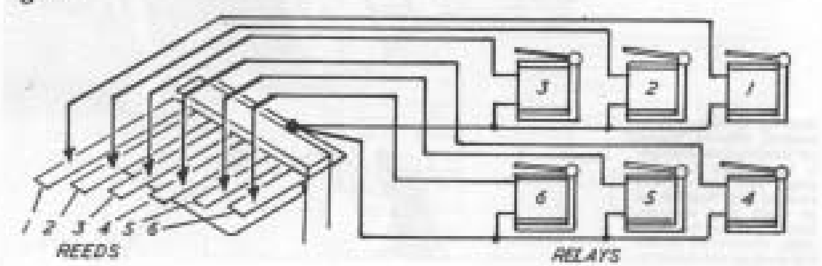
Metz 6 tuned filter super-het receiver with ready wired, plug-in servos. A four channel filter unit also plugs into the main receiver, extending its operation to 10 channels.

apart from a complication of circuitry, is that filter circuits tend to be somewhat bulky, thus increasing the overall size and weight of the receiver when more than about three channels are covered. However, this can be met by the use of suitable miniaturised components, although cost tends to be relatively high. It is also normal to use filter circuits with relays, whereas direct or relayless operation is usually preferred on modern multi installations to reduce weight and decrease the number of electrical contacts involved in switching. Tone filter circuits can, however, equally well be adapted for relayless operation.

The chief advantage of tone-filter circuits, apart from eliminating all mechanical contacts before the relay stage, is that much wider separation of the audio frequencies of the individual tones can be used to eliminate any possibility of one tone interfering with another in the receiver circuit. The actual tone frequencies employed are also usually higher than with reed receivers, hence the same transmitter cannot normally be used to operate both types of receiver.

With electro-mechanical separation the receiver signal is fed direct to a reed-relay or reed 'bank', as it is normally called. This comprises, in effect, an electromagnetic coil with a number of thin spring strips in the form of a comb replacing the conventional pivoted armature, the coil being elongated in form to cover the width of the comb. The comb has as

Fig. 18



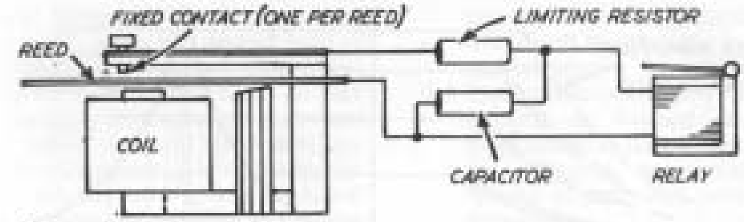


Fig. 19

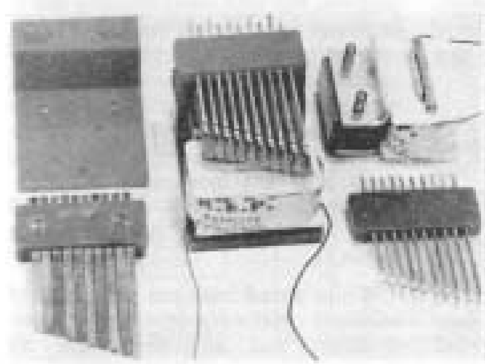
many 'fingers' or reeds as the number of tones it is required to decode. All the reeds are clamped at one end, but each is of different length with a corresponding different natural frequency of vibration, within the range of audio frequencies covered by the transmitter tones.

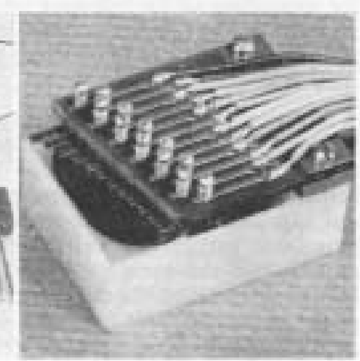
The field coil receives the 'tone' signal detected and amplified by the receiver and is thus subject to excitation by alternating current at the tone frequency. This in turn produces an alternating magnetic field or 'pull' at that particular frequency. When this corresponds to the resonant frequency of a particular reed that reed will commence to vibrate in resonance and continue vibrating for as long as that specific frequency of excitation is maintained.

In other words, the tone signal is 'decoded' in the form of strong vibration of a particular reed in the reed bank assembly capable of resonating that tone frequency. Each reed has a contact mounted above it, so that when vibrating, it touches this contact once every vibration so that a relay connected both to the fixed contact and the fixed end of the reed itself will effectively be switched 'on' and operated via the exciting current—Fig. 18.

In actual practice the period of 'make' is relatively small—usually only about 1 to 10% of the complete cycle of vibration. To help maintain a steady current through the relay to hold it operated, a capacitor is incorporated in the circuit to act as a 'reservoir'—Fig. 19. This capacitor is charged up on 'make' and then dis-

The reed bank is a delicately manufactured instrument, which is the heart of reed receivers. Below we see the components that go to make up a reed bank together with an assembled unit, in this case an R.E.P. Unit. At right, the Deans 10 reed unit, showing adjusting screws.





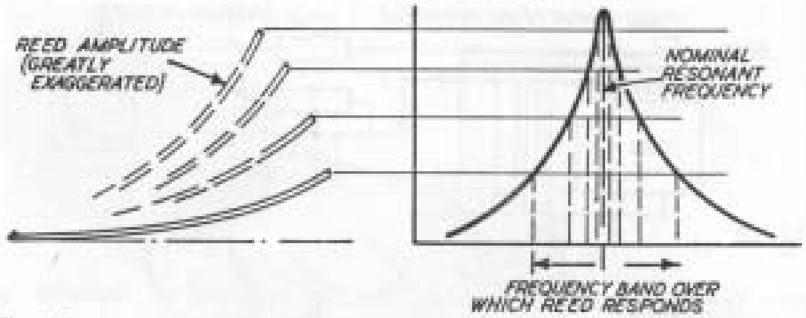


Fig. 20

charges during the 'break' period to maintain current flowing through the relay coil. The purpose of the resistor in the same circuit is merely to limit the initial or peak current when the circuit is first closed by the reed and so prevent an excessive current being passed through the reed fixed contact and the reed itself. In practice this component may be eliminated and all the resistive load provided by the reed bank or relay coil resistance.

Each reed in a reed bank is capable of controlling one relay. Thus a 6-channel receiver would have a six reed bank controlling six relays, an 8-channel receiver an 8-reed bank with eight relays, and so on. Only one element—the reed relay—is required for controlling all the following relays. In practice, however, the number of reeds which can be accommodated in a bank is limited.

Since operation of individual reeds is produced by 'resonant' vibration it will be appreciated that a reed will respond to a particular tone frequency *and* harmonics of that same tone (e.g. twice that particular tone frequency, or one half the tone frequency). It follows that all the separate frequencies of the individual reeds in a bank *must* lie within an octave as a greater spread could operate a second reed via a harmonic. The greater the number of reeds to be accommodated within an octave the closer must be the spacing between the individual frequencies and, if too close, there is the distinct possibility of adjacent reeds being operated on either side because of nearness of resonance.

Within the normal AF tone range comprising a single octave within the range of 250 to 750 c.p.s. this virtually limits the maximum practical number of reeds in a bank to 12, and even this is likely to lead to some inter-reaction unless meticulous care is taken in the design and construction of the reed bank. Spacing of the individual reed frequencies is usually uniform, but with some opening out at each end (or towards the longer reed end) to arrive at optimum performance. The actual shape of the reeds, method of mounting, contact position and adjustment all have an effect on the 'sharpness' of tuning of individual reeds and the possibility of over-lapping. Some typical data on reed bank frequencies are summarised in Table II.

Whilst a reed bank can be capable of excellent performance, design, construction and adjustment are all

critical features. Not all commercial reed banks reach the desired level of reliability, sharpness of tuning and stability, and those that do are inevitably quite expensive. Low cost reed banks, or home made units, are seldom satisfactory. For this particular duty, only the best is good enough, and will represent an economy in the long run.

Primary design factors involved in the reed comb itself are:

(i) Material suitability—to have the required 'spring' characteristics and be unaffected by temperature changes or fatigue effects which could cause the resonant frequency to drift.

(ii) Electrical suitability—since the reeds act as contacts, so must have good electrical conductivity and freedom from corrosion which could cause increasing contact resistance.

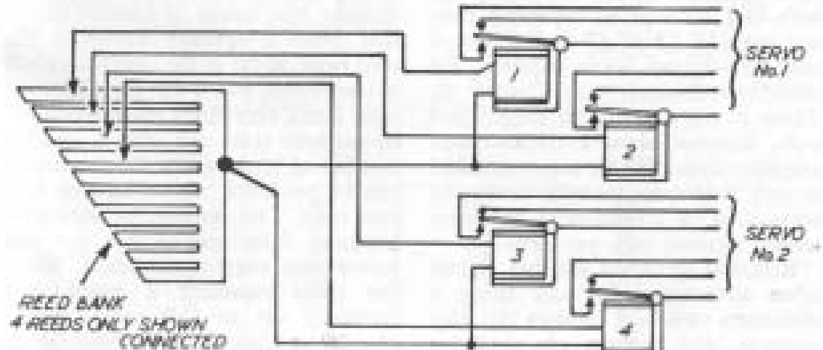
(iii) Rigidity—so that each reed is cleanly and rigidly anchored at its fixed end so as not to dissipate energy. Also there is the fact that any change in end anchorage condition, however, minute, could modify the effective length and thus the resonant frequency.

(iv) Exact dimensions—so as to be cropped or finished at the exact resonant length required for optimum or near-equal spacing of individual resonant frequencies.

In addition the magnetic circuit must be as efficient as possible as governing the sensitivity of the reed bank, its efficiency of operation and the contact pressure achieved. Contact position is also important as this can affect the sharpness of tuning of individual reeds.

This is because no practical reed will resonate at an exact 'spot' frequency but rather will tend to resonate or vibrate over a range of frequencies with peak amplitude at the true resonant frequency. On a working reed bank the actual amplitude is limited by the reed striking the contact. The nearer the contact to the reed the less the 'free' amplitude available to the reed and the broader the band width over which contact is likely to be made—see Fig. 20. The sharpness, or otherwise, of the peaked curve will

Fig. 21



be dependent on the reed geometry and end fixing to start with. The only way to further increase the selectivity of the reed is then to interrupt the free amplitude at as high a level as possible —i.e. space the contact as far away from the reed as possible. At the same time this may result in only minimal 'make' time for completing the relay circuit. This can be offset somewhat by moving the contact position in from the end of the reed when closure time can be increased from about 1% to 8 to 10% without material affecting the amplitude.

The basic circuit extracted from the reed bank is quite straightforward. The fixed ends of the reeds normally have a common connection (or are split into two equal banks insulated from each other), which also becomes a common connection to each relay. Each individual reed contact is then taken to its appropriate relay—Figs. 18 and 21. Servo circuits are then wired separately to each relay.

Alternatively—and this is usually preferred on modern systems—individual reed connections are taken directly to a transistorised current amplifier circuit associated with the servo, thus dispensing entirely with the chain of relays. Since one relay is required per channel this saves considerable bulk and weight. On the other hand a suitable amplifier to go with each servo is an expensive item and can add £3 to £5 to the cost of each servo (one servo required for every two channels—see Chapter 4). There is still a saving in weight and bulk, however, since a transistorised amplifier circuit can be accommodated in very little space (usually inside the servo itself) at a fraction of an ounce weight increase only, per servo.

Relayless operation also has several other advantages. For one thing it eliminates switching through the relay contacts, and contacts are always a potential source of trouble. Also it eliminates the necessity of having the relays properly adjusted, or the chance of relay adjustment or relay working being upset by a crash. Yet another advantage is that the output handled by the reed contacts is appreciably lower so that these contacts are operating under much more favourable conditions with less chance of failure due to 'burnt' contacts.

For example, when a reed bank is connected to relays, the actual current carried by the reed contacts is considerably higher than the nominal operating current of the relays themselves, due to the low duty cycle involved. Thus with a 5% duty cycle and a relay drawing 10 milliamps, peak current values of 200 milliamps will be carried by the reed contacts. The resistor, included to limit the peak current, must be fairly low in order to obtain the necessary current through the relay coil. A typical value is 47 ohms.

With relayless operation the output power handled by the reed contacts need only be of the order of 0·2 milliamps, which is fed directly to the current amplifier stages in the servo circuit. The resistor used in this case can be quite high—typically 470 ohms —so that the absolute peak current carried by the reed bank is quite low.

The conventional relayless reed-type receiver also scores in another direction. Since it virtually finishes as the reed bank, as far as the internal circuit is concerned, and a 10- (or 12-) reed relay is not very much more expensive to produce than one with a smaller number of reeds, a 'standard' receiver can be produced with a 10- (or 12-) reed bank. This can then be used with anything from one to five (or six) servos with current amplifiers. Since the latter represent a major cost (typically up to £10 each), multi-channel operation can be built up in '£10 stages', as it were. Equally, virtually the same receiver (of suitable circuit design) could be used to operate a relay (for single-channel) and later converted to work as a multi-channel receiver by replacing the relay with a reed bank—the additional cost of converting to 'multi' merely being that of the reed bank (and more or less directly proportional to the number of reeds in the bank).

Stage building, where a basic receiver unit can be added to build up more channels progressively is also a feature of certain types of Continental 'multi' equipment, employing plug-together circuit stages. Thus the Grundig basic receiver (super-regen or superhet) can accept one, two, three or four filter units plugged on, each filter unit providing two channels of signalling via relay contact outputs.

Recommended 'spot' frequencies agreed between American and British authorities cover 13 separate 'spots', with colour coding as listed under. The colour code is intended to provide a ready method of displaying operating frequency by flying a pennant of the appropriate colour from the aerial. The transmitter will be fitted with a crystal of the appropriate 'spot' frequency and the receiver with a matching crystal of frequency equal to spot frequency *minus* receiver IF frequency (which may be 455, 465 or 470 kilocycle/second in conventional practice).

TABLE I. SPOT FREQUENCIES FOR SUPERHET OPERATION

Spot	*Frequency mc/sec.*	*Colour code*
0	26·970	black
1	**26·995**	**brown**
2	27·020	brown/red
3	**27·045**	**red**
4	**27·070**	**red/orange**
5	**27·095**	**orange**
6	27·120	orange/yellow
7	**27·145**	**yellow**
8	27·170	yellow/green
9	**27·195**	**green**
10	27·220	green/blue
11	**27·245**	**blue**
12	27·270	white

Note: In practice interference is highly likely between equipment operating on adjacent 'spots'. The normal allocation of spot frequencies embraces the numbers shown in heavy type.

Not all superhet transmitter-receiver combinations conform to the above allocation of spot frequencies. Thus the original Grundig equipment differed in offering five separate spots chosen by the manufacturer with the following values and colour coding:

spot 1	26·975	(black)
spot 2	27·265	(white)
spot 3	27·097	(yellow)
spot 4	27·120	(red)
spot 5	27·143	(green)

Telecont spot frequencies are:

spot 1	27·120	(black)
spot 2	27·220	(red)
spot 3	27·020	(green)

TABLE II. REED FREQUENCIES (10-CHANNEL BANK) (C.P.S.)

Channel	*Frequencies with Equal Increments in Reed Length*	*Constant Frequency Spacing*	*Optimum Spacing*
1	250	250	250
2	269	275	268
3	284	300	287
4	300	325	308
5	319	350	330
6	342	375	354
7	368	400	379
8	396	425	406
9	425	450	435
10	461	475	467

MULTI SERVOS

CHAPTER 4

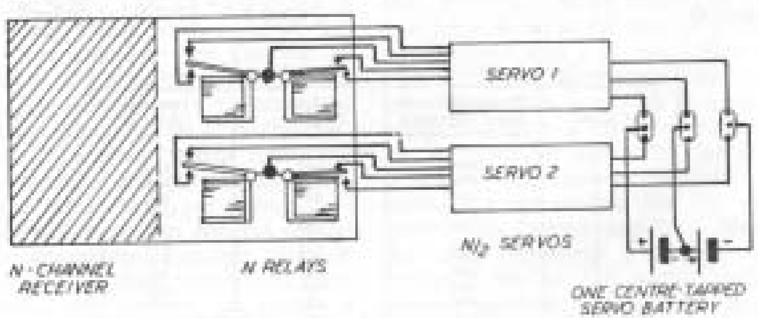
The general term *actuator* describes all types of devices capable of turning an electrical signal into a mechanical output or force to move a control. Normally all actuators are electro-magnetic devices, the simplest of which are escapements. Escapements are virtually electro-mechanical 'switches' with an external source of power provided by a rubber band 'motor', and all are designed for operation via a single radio channel. Actuators based on an electric motor are self-contained, as it were, with built in switching to provide the required response to being energised, either directly or indirectly, by the receiver signals. They can be designed for either single-channel or 2-channel operation, and are normally referred to as 'motorised actuators' or *servos*.

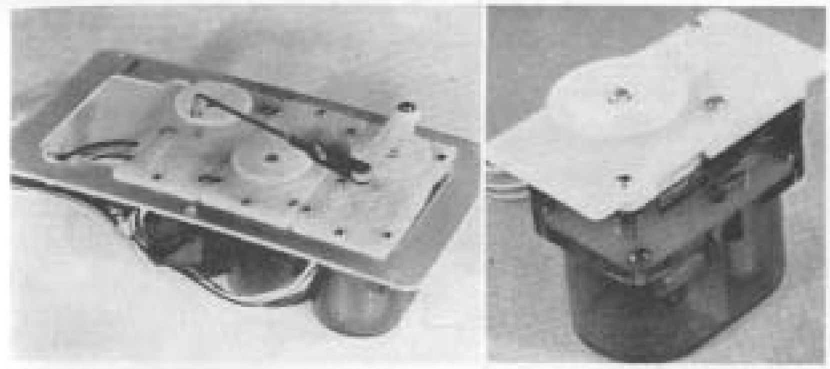
A 'multi' receiver with 'N' channels is capable of operating 'N' single-channel servos (or escapements); or 'N/2' two-channel servos. Servos are invariably preferred to escapements and, for 2-channel operation, must be used. Similarly, it is always preferable to operate 2-channel servos from a 'multi' receiver since this halves the number of servos required. There are, however, exceptions, such as in model boat installations, where a 2-channel servo may be used for the main control(s) and single-channel servos for additional services.

Regardless of the method of switching, the action of a conventional 'multi' (2-channel) is always the same. With *indirect* switching the servo and servo batteries form a separate circuit external, to the receiver, with connection to the receiver via the contacts of the two relays—Fig. 22. Operation of relay 1 then closes the external circuit in such a manner as to cause the servo motor to drive in one direction. Operation of relay 2 closes the external circuit with opposite battery polarity through the servo motor to cause it to drive in the opposite direction. With either direction of drive, a built in switching system (or equivalent mechanical control) in the servo unit limits the amount of drive in either direction, so that if a signal is held on, the motor will drive an output arm to a maximum displacement, where it will stop—equivalent to full control position. Additional built-in switching (or equivalent mechanical control) also provides that when the signal is released and the relay contacts change over the output arm will either be driven back to its original neutral position (self-centring action); or stop where it is (progressive action).

The servo battery is centre tapped to provide two opposite voltage supplies for driving the servo motor in either

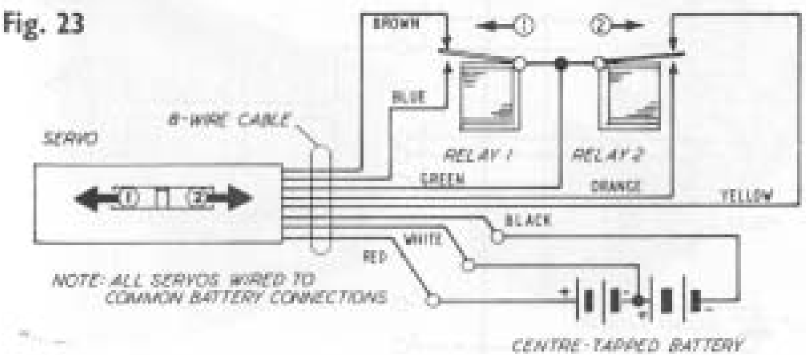
Fig. 22

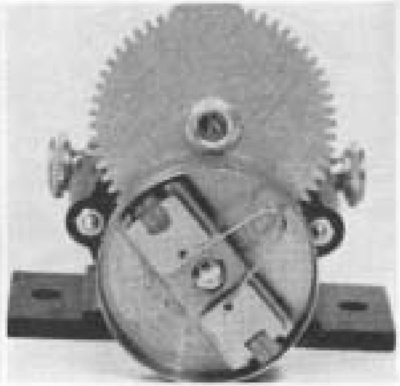




Japanese M.K. multi servos are plastic cased, with rotary output drive. Above are three units mounted on a convenient installation plate, which is also a commercial item. Note 'trim bar' arrangement.

Fig. 23



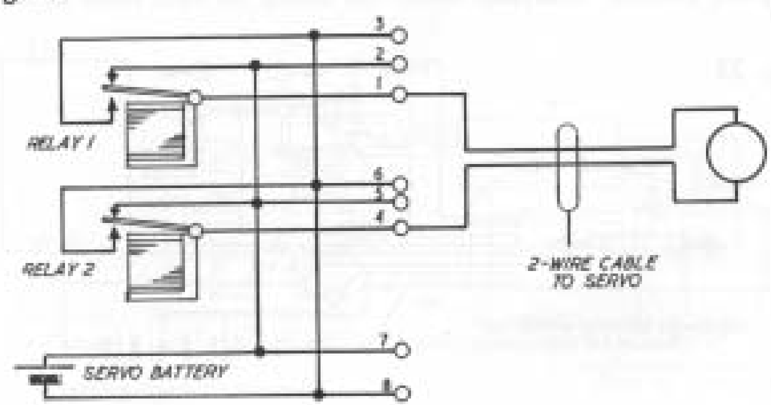


Rising 'Centrifugal Clutch', multi servo. Close-up of clutch shows bob weights which engage with clutch when servo motor rotates—disengage when signal is terminated. Servo is spring centred.

direction, according to the switching alignment as governed by the relay contact positions and the servo switching panel swept by wipers. The standard system then involves eight wires from the servo, connected as shown in Fig. 23. No switch is necessary in the servo circuit since battery on-off switching is provided by the relays. Wiper switching action is normally as shown in Fig. 29, although the actual geometric layout of the switch board contacts and wipers may vary considerably with different servo designs—e.g. the mechanical action may be linear, semi-rotary or full rotary.

In some cases the servo circuit may be simplified by accommodating internal connections so that the number of external wires to the servo can be reduced. This can apply to the servo design itself, or at the receiver end as far as the relay output connections are concerned, or both. Thus in the Grundig system the number of external wires running to each servo is reduced to two, the matching servo in

Fig. 24



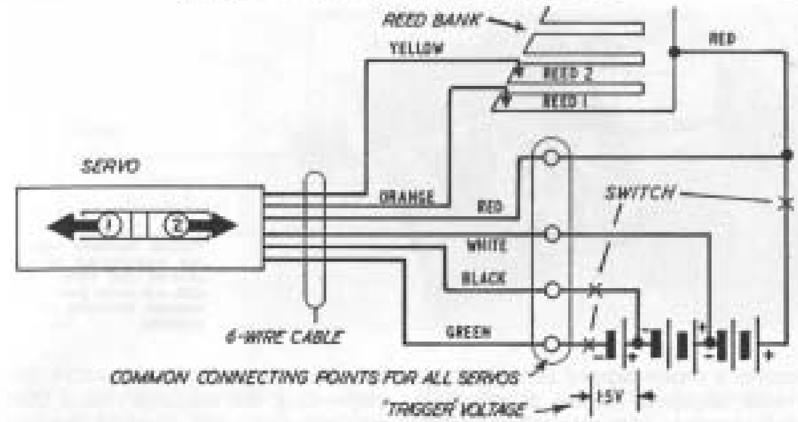


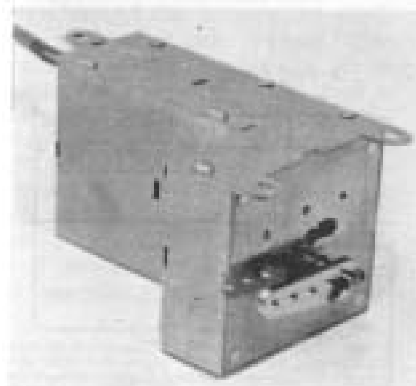
Fig. 25

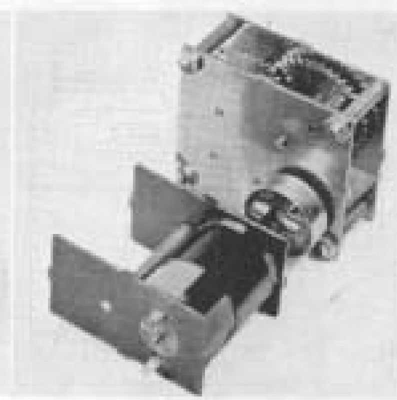
this case being spring return and 'changeover' output connections produced by internal strapping in the plug so that only a *single* servo battery is required—Fig. 24.

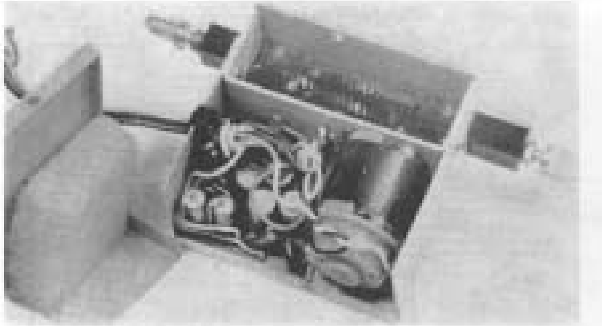
This particular circuit can be used for two-wire operation of any *spring return* mechanical-limit 'multi' servo controlled by two relays and requires the use of one servo battery only (not a centre-tapped battery). Note, however, that in the case of the Grundig system where connection to the filter unit is made via an 8-pin plug, if a conventional (8-wire) multi servo is to be connected an *additional external wire* will be needed to accommodate a centre-tapped battery and *only* plug points 1 and 4 need to be commoned (which means, in effect, that one of the eight wires in the plug-in cable is spare, hence the additional external wire to make up to a conventional 8-wire system).

With a relayless output from the

Graupner Duo-Matic centrifugal clutch multi servo. View with case removed shows motor gear train and clutch. Servo is of sturdy construction with plenty of power.





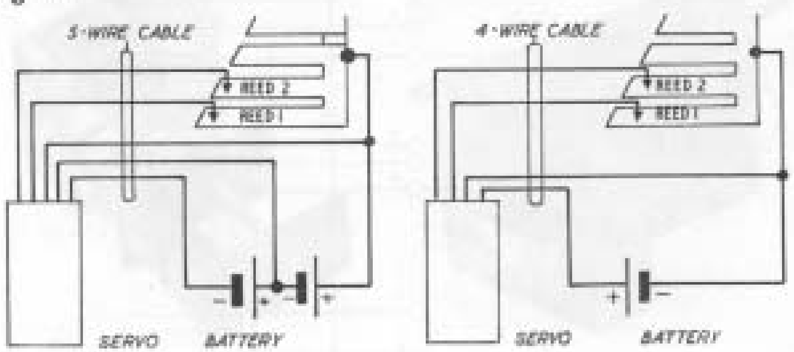


Ripmax Maximite relay-less transistorised servo, showing gear train with rack and pinion gears and compact transistor servo amplifier.

receiver a centre-tapped servo battery is still required (unlike a relayless *single*-channel receiver which may operate its actuator direct from the receiver current). A current amplifier is also essential, combined with the servo circuit to provide the switching function and the amount of current needed for powering the servo motor. Physical switching of servo motor limits and self-neutralising is provided by a switching board traversed by wipers, as in the servo used with a relay output. The servo is, in fact, identical but for the addition of the servo amplifier. However, the battery requirements may be modified to include a further 1·5 (or 1·2) volt 'trigger' battery for the amplifier circuit—Fig. 25. There are, however, two less wires from the servo (incorporating the amplifier) since there are only two reed contacts involved (external to the servo) and one common connection to the reed bank comb instead of six relay contacts to be connected. This actually saves three wires, compared with a relay-type hook-up, but with the relayless circuit there is an additional connection to the extra 'trigger' battery.

The conventional multi servo with built-in amplifier for relayless operation, therefore, is normally connected via a six-wire system i.e. six wires emerge from the servo, normally following the standard colour code shown in Fig. 25. If the amplifier circuit is designed to work without

Fig. 26



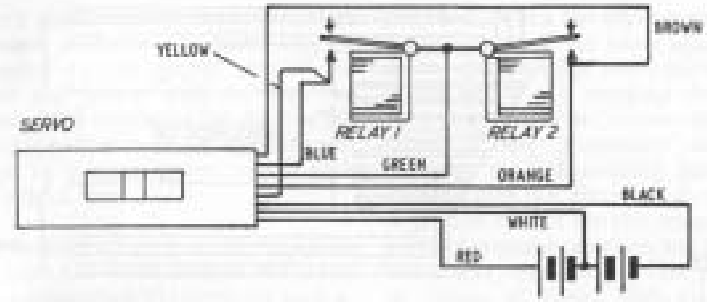


Fig. 27

'trigger' voltage the number of leads can be reduced to five; or if designed to work off a *single* battery, the number of leads can be reduced to four—Fig. 26. This affects *only* the number of connections to be made to the reed bank (minimum three) and the battery and size of battery and not the receiver.

The current amplifier is invariably an all-transistor circuit and normally designed to be accommodated within the servo case. This is usually most convenient, but not the invariable rule. A bank of servo amplifiers (one for each two channels) may be mounted as an intermediate item between the (relayless) receiver and the (normal) servos. This system has the advantage that receiver and amplifier bank may be changed from model to model, leaving the servos permanently mounted. Thus a set of normal servos only is required for permanent installation in each model at a saving in cost of one amplifier per servo (which would be necessary if just the receiver was swapped from model to model). The use of servos with built-in amplifiers is more normal for use with relayless receivers, however. In any case, fuselage servos are usually mounted on a tray which makes transfer from one model to another a fairly straightforward operation—see Chapter 8.

If intended for 'progressive' action the necessary amplifier circuit can be simplified somewhat, with a reduction in cost. Servos with built-in amplifiers for relayless operation may, therefore be produced in separate 'self-centring' and 'progressive' forms, with the latter costing slightly less. Equally, a 'self-centring' servo for relay operation can be adapted for 'progressive' action merely by omitting to wire up, or disconnecting, the self-centring

Bones of the matter. Complete mechanism of the M.K. servo from Japan, showing motor, gear train and transistorised D.C. amplifier. Complete assembly slips into case.

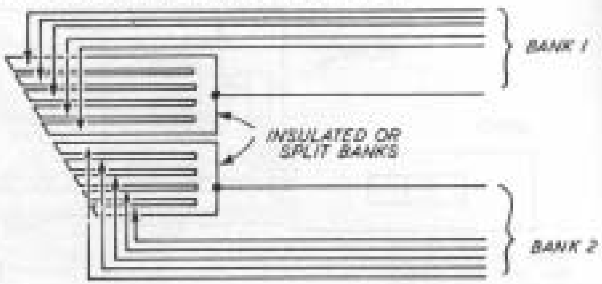


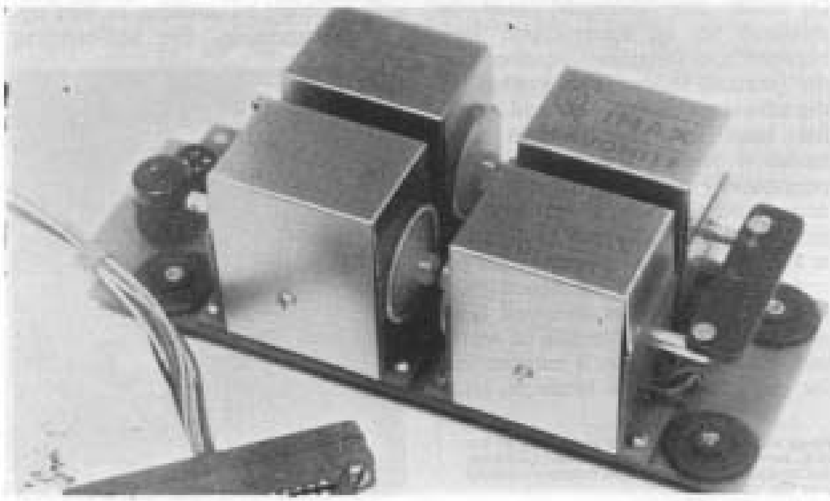
Fig. 28

circuit—Fig. 27. In the case of a servo with built-in amplifier for relayless operation, and the amplifier designed for self-centring action, conversion to 'progressive' action normally involves breaking (i.e. cutting) an internal wire which, in effect, disconnects the self-centring part of the switcher board.

In some cases the reed bank is designed on a split basis—i.e. two separate halves electrically insulated from each other (see Fig. 28). This enables the 'simultaneous' output circuits to be isolated from one another. Some servos are designed to operate specifically with split reed banks; others may not be suitable for use with a split bank, unless the two halves of the bank are commoned (i.e. connected together to form a normal reed bank switching circuit).

The majority of modern multi servos incorporate built-in electrical switching for providing 'stop and hold' at full control positions on either side, and self-centring action on release of signal. The switching system normally comprises a suitable printed

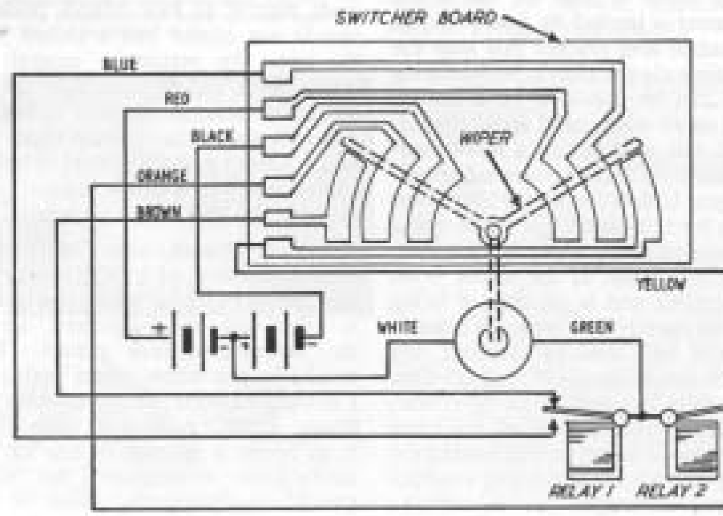
For convenience servos are often mounted on installation boards, permitting easy transfer from model to model. This pack, for a 10 channel installation uses a printed circuit baseboard, into which servos, power pack and receiver are wired. Unit made by E & L Developments using their Climax servos.

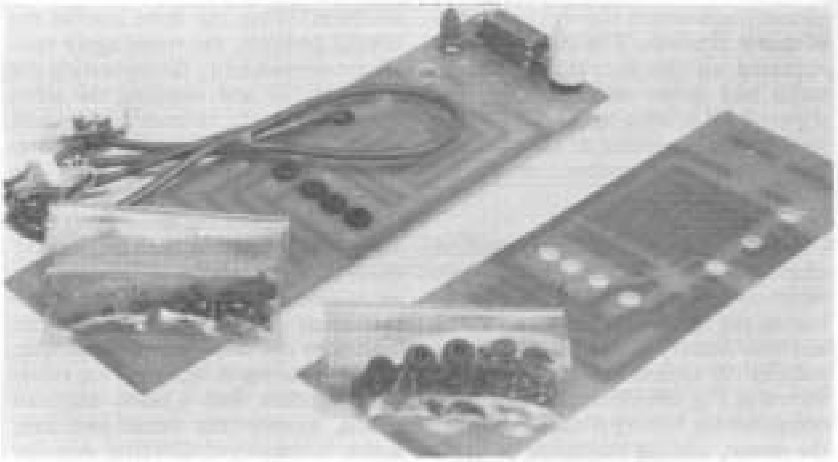


circuit panel which is swept by a series of wiper contacts. The panel may be mounted on the output arm of the servo and rotate with it, with the wipers fixed relative to the case; or the switch panel mounted to the case and swept by a wiper system moved with the output arm.

Switching action is usually based on employing all three contacts of the two relays controlling the servo (or equivalent in the case of relayless operation) and two battery supplies of opposite polarity. A typical circuit is then as shown in Fig. 29. Operation of relay 1 completes the battery B circuit through the motor, causing the motor to drive in one direction. On reaching the limit of the control movement required, the wiper runs off the 'supply' contact strip so that motor drive ceases although the relay is still held in by the signal. On release of signal the relay drops out. This completes a circuit through battery A and the motor to drive it back in the opposite direction. When the drive reaches the neutral position, the wiper again runs off the contact strip, disconnecting the motor circuit and stopping the servo in neutral ready to receive the next signal. If only 'progressive' action is required the self-centring leads are disconnected (i.e. the wires to the top contact of each of the two relays). The servo movement can then be 'inched' either way, remaining in that position on release of signal, with maximum movement in either direction still limited by the 'stop' or limit switching. When the servo is designed for relayless operation with a servo amplifier added, exactly the same switching action is employed (i.e. the switcher board and mechanical side of the servo is exactly the same). The servo amplifier circuit becomes, in effect, an extension of the switcher board to give either self-neutralising or 'progressive' action from the servo. The former circuit can be modified to 'progressive' action by disconnecting the self-centring switching lead. A

Fig. 29





More etched circuit servo installation boards, this time for Danner servos. Note that receiver connector, battery connector and jack plug for charging are soldered direct to board.

servo amplifier designed purely for 'progressive' action cannot, however, be adapted to provide self-centring action without an extension of the circuit.

Other multi servos may employ mechanical limit switching, such as a slipping clutch which allows the motor to keep driving as long as a control signal is held on but actual movement is limited by a stop. When the control arm reaches this stop the drive slips via the clutch. Self-centring action can be provided by a spring, giving an all-mechanical servo control. Whilst this may permit a more compact assembly there are certain disadvantages. Unless the motor is on open circuit for self-centring it will act as a regenerative brake, slowing the return time appreciably. If the motor is on open circuit and is capable of being returned rapidly by a spring of suitable power it will tend to over-run and oscillate somewhat about neutral before being fully damped. Also, of course, with spring return, part of the servo output power is lost in overcoming the spring action when moving to a control position, although this is not so serious a problem with the relatively high reduction gear ratio normally necessary between the motor spindle and the output arm.

Quite rapid action is required for aircraft control systems. Transit time from neutral to full control position should not exceed half a second (and the same for return to neutral) as otherwise it will become increasingly difficult to maintain smooth control—e.g. with a slow transit time there will be a tendency to over-control or hold a control on longer than required because of the slow initial response.

A slow transit time may be a characteristic of relay operated spring-return servos where the motor is effectively short-circuited during the return-to-neutral period. This results in the servo motor acting as a self-regenerative brake, opposing the spring action. A cure in such cases is to insert a resistor in one of the motor leads to eliminate the 'short circuit' condition, the value of the

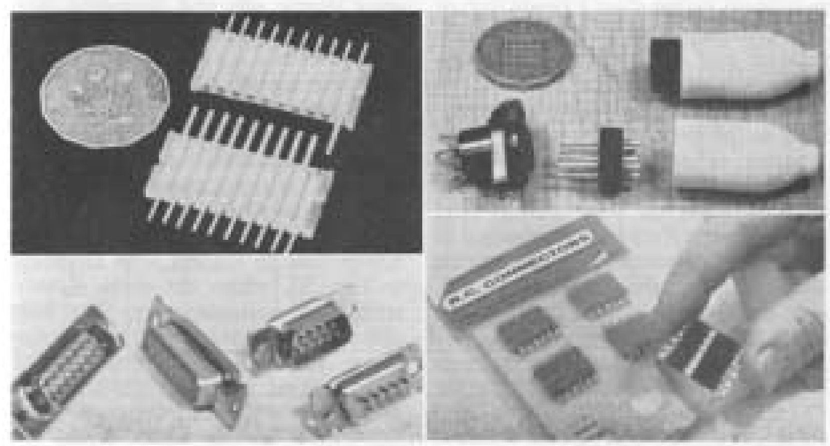
resistor being selected by trial and error to establish a suitable transit time (a suitable value will usually be of the same order as the coil resistance of the motor). In order to compensate for the additional resistance in the motor circuit for normal driving it may be necessary to increase the servo battery voltage—e.g. if the resistor has the same value as the motor coil resistance, then the servo battery voltage would need to be doubled to restore the original value of current flow through the motor.

Whilst all multi servos are basically of similar overall design—and differ only in type and method of gearing and switching controls—the ultimate reliability of the servo depends primarily on the quality of its motor, and in particular the behaviour of its brushes and commutator. Particularly with relayless operation, increasing brush resistance will tend to cause a motor to run sluggishly, or stick in a certain position because the current output from a servo amplifier is limited and excessive brush resistance will simply mean a reduction in current through the motor. It is not possible to 'boost' servo motor power with relayless operation by increasing the receiver battery voltage as this could overload and damage the circuit components.

With relay operation using a separate servo battery, battery voltage can, of course, be increased if servo action is too sluggish. Thus servo action is generally less critical as regards motor condition with this system. However other troubles may arise for, if the servo battery voltage is too high, the current carried by the receiver relay contacts may be excessive, causing burning or pitting and ultimate failure to operate as circuit switches.

The multi servo is a critical component of the radio control installation and is almost invariably bought rather than home made. The best of commercial servos have been developed to a high degree of reliability and are capable of long and satisfactory service when used within the limits of recommended voltages, etc. Not all commercial servos are, however, entirely reliable, and some are distinctly unsuitable for critical applications, such as a main flying control.

Although some modellers prefer to wire their equipment without the use of connectors, most prefer the convenience connectors offer. Below are some types popular for R/C installation work.



MULTI PROPORTIONAL SYSTEMS

CHAPTER 5

The equipment described in Chapters 2, 3 and 4 forms the basis of all conventional 'multi' systems operating 'bang-bang' controls (via self-centering servos) or 'trim' controls (via progressive-action servos). Proportional control systems are quite different in that they provide infinitely variable control response with synchronisation between a control stick (or equivalent) movement and mechanical response of the control surface it governs. It will be appreciated that the method of signalling must be quite different for the transmitter must provide a means of signalling an infinitely variable *degree* of control movement rather than a single 'on' or 'off' command, with decoding at the receiver end similarly more complex.

Given a variable signal there are two basic methods of providing corresponding or 'proportional' response via an actuator or servo. In the so-called 'open loop' system the mechanical movement of the servo output (and thus the control surface) is arranged to be directly proportional to the current fed to it. This is the simplest approach, but one which suffers from severe practical limitations. Applied to any aerodynamic control surface (such as rudder, elevators or ailerons), or the rudder of a boat, the actual control movement achieved under normal operating conditions can differ appreciably from the theoretical or signalled position, due to 'blow-back'. This, quite simply, is a reduction in actual control movement achieved by virtue of air pressure (or water pressure in the case of boats) on the control surface once displaced. Thus an open-loop system can never provide true proportional control movement, except under static conditions, and the amount of blow-back will be variable with load on the control surface moved.

This inherent limitation can be overcome by using the servo in a 'closed loop' circuit where the *actual* position of the servo is measured in some simple way and compared with the theoretical position as signalled. Any difference is rendered in terms of an 'error signal' which further energises the servo circuit to drive the servo into a position where the error signal falls to zero—i.e. the servo has achieved a synchronised or true proportional position.

The working of a closed loop system can be studied with reference to Fig. 30, where the servo is controlled by a single relay. The only difference between this particular servo and a conventional 'multi' servo is that it is mechanically connected to a potentiometer so that movement of the servo drives the

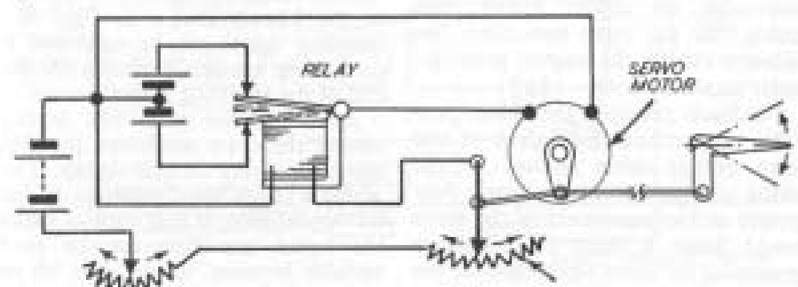
Orbit four function analog proportional control system provides fully proportional control of rudder, elevators, ailerons and throttle, with trim on elevator and aileron functions. Here we see complete system, showing layout of transmitter controls. Rudder and elevator on left, ailerons on right stick. Throttle lever at top right of case, elevator trim top left and aileron trim lower centre.

potentiometer arm. The servo motor is energised to drive in one direction when the relay armature is 'out', and with opposite polarity to drive in the other direction when the relay armature is pulled in. If the armature floats between the two relay contacts the motor is switched off.

Suppose, for the sake of simplicity, the relay is adjusted to pull in at 2·2 milliamps and drop out at 1·8 milliamps. A 2·0 milliamp current through the relay coil as an 'input' signal will then cause the armature to float in a mid-way position, switching the motor off, this condition being established by adjusting the position of the control potentiometer.

If now the control potentiometer is turned to reduce the resistance in circuit the current through the relay coil will rise and, once it has risen above 2·2 milliamps the relay will pull

Fig. 30



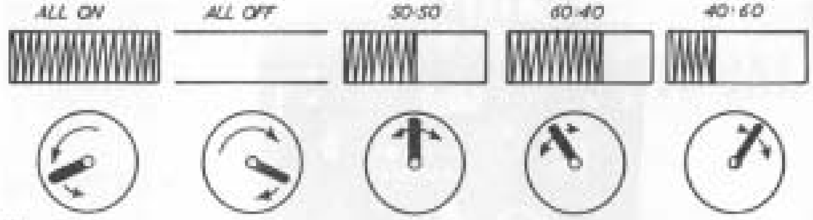


Fig. 31

in. This will complete the battery circuit through the motor, causing the servo to start driving in one direction. At the same time the servo will drive the feedback potentiometer increasing its resistance in the circuit until, at a certain point of movement, the increased resistance in the circuit will have dropped the current through the relay coil to 2 milliamps again. At this point the relay armature will move out to mid position, switching off the motor and stopping the servo in that position. The amount of movement will correspond exactly to the 'control' movement—i.e. with the same values both for the control potentiometer and feedback potentiometer the amount of movement on the control potentiometer to initiate servo movement will be followed by exactly the same amount of movement of the feedback potentiometer (driven by the servo) to bring the circuit back to the same initial condition of balance. Since feedback potentiometer and servo movement are rigidly linked, this means that the servo movement has followed exactly the control potentiometer movement.

Feedback control, therefore, provides proportional movement of the servo output drive relative to the actual change of input signal. Any greater or less movement of the servo would leave a state of unbalance generating an 'error signal' so that the servo would continue to drive, one way or the other, until the balance or 'null' condition was reached.

The basis of a proportional control system is, therefore, to operate the servo on a closed loop circuit so that, with a continuous signal applied, the servo will always seek and find a 'balanced' position. Any variation in the input signal producing unbalance will then be countered by the servo moving to a new position *proportional* to the signal difference. The effect of blow-back is eliminated since any restriction of proportional movement means that an error signal still remains in the circuit so the servo will continue to drive until the full proportional movement has been achieved to cancel the error signal. It is usually also necessary to provide some form of damping to prevent the servo motor over-running the 'null' position and so hunting about the balance position. This may be done by applying mechanical or dynamic braking across the motor itself, or by providing a separate damping signal. For example, in the circuit shown in Fig. 30 a damping signal can be produced by connecting a motor brush to the free end of the feedback potentiometer.

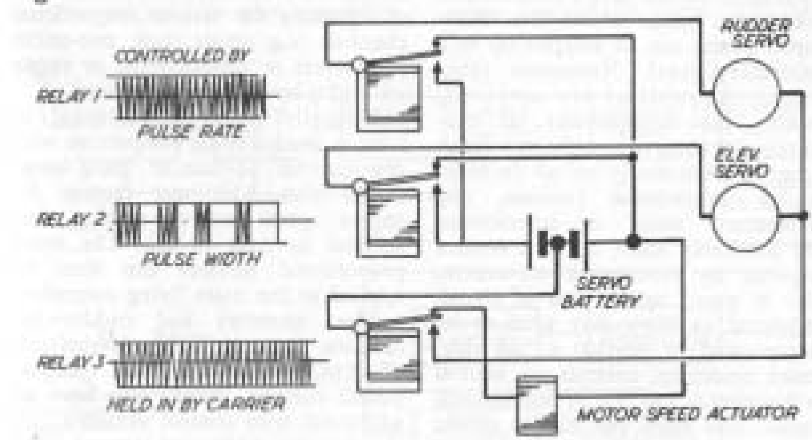
As far as the radio side is concerned there are numerous possibilities for applying variable signals. Thus whilst a single 'tone' provides an 'on-off' signal only, if that tone is *pulsed*, the signal condition can be made variable between 'all off' and 'all on' with an infinite variation of 'mark' to

'space' ratios between—see Fig. 31. Applied to the circuit of Fig. 30 it will be appreciated that this is capable of providing infinite variation in relay armature 'dwell' times on either the upper or lower contact, with equal mark-space ratio corresponding to a 'neutral' position with the armature central between the two contacts.

Theoretically, at least, one pulsed tone signal could be used for obtaining proportional rudder control; a second pulsed tone for proportional elevator movement; and so on. In practice, however, pulsed tone signalling is seldom carried beyond two channels (dual proportional) particularly where simultaneous operation of the two control surfaces is required. For extension to further control coverage, rather more sophisticated systems are normally employed. Thus a triple-proportional system may work on one (or two) tone channel(s) variable by pulsing and two (or one) channel(s) variable in *frequency*; or three independent tone channels all variable in *frequency*. Quadruple proportional may be arrived at on a similar basis; or perhaps just two (proportional) channels variable in frequency, a third proportional channel provided by varying the *symmetry* of the tones transmitted; and the fourth proportional channel derived by varying the repetition rate. The latter method was used in the first of the modern quadruple-proportional systems to achieve marked success (Space Control).

The possible alternative methods available for both proportional signalling and decoding at the receiver are numerous, and new commercial equipment continues to appear. In the main these are of 'digital' or 'analog' type, the distinction between the two being, in simple terms, that a digital system operates on a given number of pulses sent out by the transmitter and decoded by the receiver; and an analog system works on a 'logic' signal transmitted in terms of pulse width. As far as the user is concerned the electronic system employed is immaterial. It is the working of the transmitter-receiver-servo combination which matters since proportional equipment is (almost) invariably supplied in the form of complete

Fig. 32



One of the first really successful proportional systems—Walt Good's dual proportional.

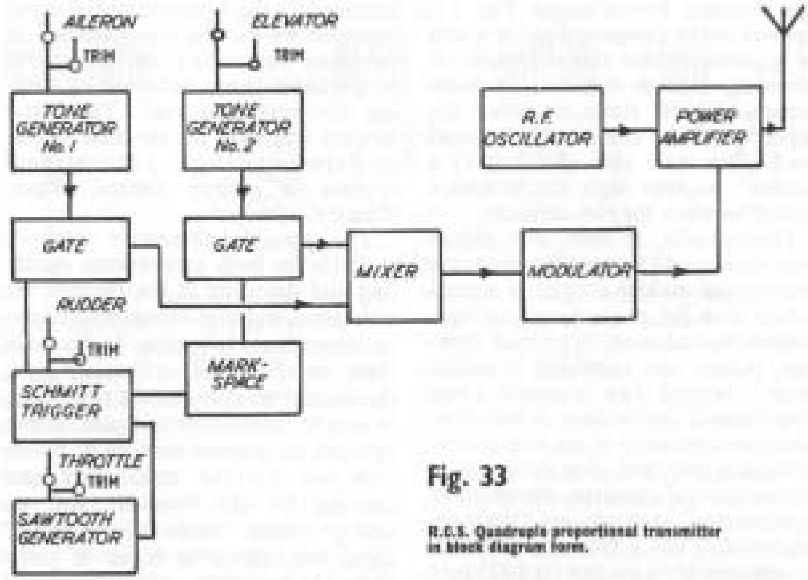


Fig. 33

R.C.S. Quadruple proportional transmitter in block diagram form.

working units which have merely to be plugged together.

The necessary electronic circuitry is relatively complex and, to achieve compactness and minimum weight, all-transistor circuitry is virtually essential. This can have a considerable bearing on range unless the transmitter power can be stepped up to a satisfactory level. Numerous other technical problems are involved, notably the susceptibility of proportional systems to interference. Since a control is effectively 'on' all the time, in its proportional position, any momentary 'noise' or interference will inevitably show up as a control response by momentary movement. Also to guard against loss of signal, additional circuitry may need to be incorporated to provide a 'fail safe' action returning controls to neutral in the event of loss of true proportional signal. This again can lead to erratic response with a receiver circuit prone to interference operated in an area or under conditions where 'noise' is prevalent.

There is also the question of how many proportional channels are necessary, what additional features they should have (if any), and the method of signalling the various proportional channels (e.g. single stick, two-sticks plus levers or pushbuttons, or single stick plus levers or pushbuttons).

Basically, triple-proportional, at least, is needed to be competitive with conventional 10-channel 'bang-bang' multi, plus additional facility for engine speed control—making four services covered in all. The main proportional services can then be applied to the main flying controls—rudder, elevators and rudder—for *complete* control. To be completely effective, each of the main (proportional) controls should also have an additional trim control available (i.e. the desirable additional feature). This

will then make the control available equivalent to that which would require 14-channel 'bang-bang' multi; and also superior in response by providing a full range of *proportional* control positions plus separate trimming facilities.

The only disadvantage is that by increasing the number of proportional channels the complexity and cost of the equipment goes up considerably. Proportional control systems offering 'minimum' coverage thus have their particular attraction in lower cost. This may, in fact, be directly comparable with the total installed cost of conventional 10-channel 'bang-bang' multi.

Dual-proportional plus one additional service is obviously the simplest system (i.e. 2 + 1). The two proportional channels are then allocated to the main services—i.e. elevators (essential) and either rudder or ailerons; and the one (speed change-over) control to engine speed. This will provide a flyable proportional system, but it will not have the same degree of complete control over manoeuvres and flying attitude of the model as 10-channel 'bang-bang' multi. In other words, it will not be competitive as regards manoeuvrability, but it may well be competitive in cost. 2 + 2 (with two channels available for 'progressive' engine speed control is better without being very much more complex).

The *2 plus* system can be improved by coupling elevators and rudder as a paralleled proportional control—i.e. both respond together to the same proportional signal. This only needs one additional proportional servo, paralleled into the chosen channel output. It is also possible to arrange for this paralleled service to be switched in and out mechanically—say making rudder available under certain conditions and switching out the rudder servo in favour of the aileron servo connected to that channel for all other conditions. The latter enables the aileron control to be used more effectively than in the case of coupled aileron and rudder where, for certain manoeuvres, a coupled rudder will act in the opposite manner to that required (and no rudder movement at all would be better).

The 3 + 1 system provides complete control, as noted above. If it becomes a true quadruple-proportional system (with trim), i.e. 4 + 0 the engine throttle control also becomes proportional rather than pro-

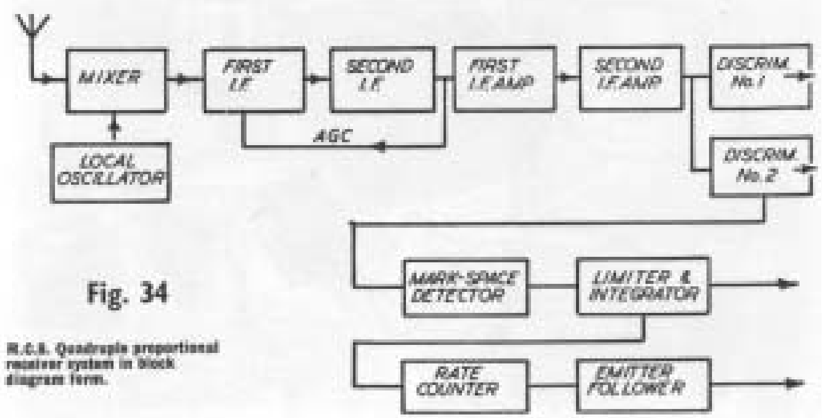


Fig. 34

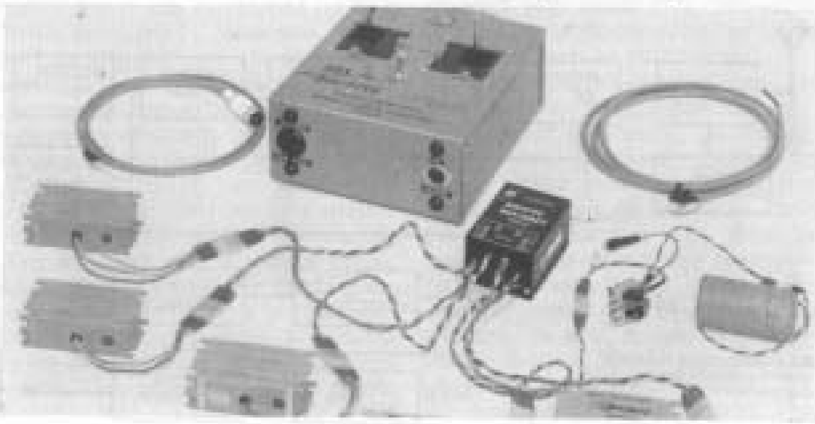
R.C.S. Quadruple proportional receiver system in block diagram form.

gressive, which has some advantage and certainly offers yet another facility not available with 'bang-bang' multi signalling. Equally, to have a proportional throttle control available with a triple-proportional system coupled aileron and rudder may be used; or separately switched aileron or rudder, as noted above. It is possible to provide more than four proportional channels although they are not directly usable as functional controls unless adopted specifically as separate trim controls; or four or more proportional controls plus additional 'progressive' controls.

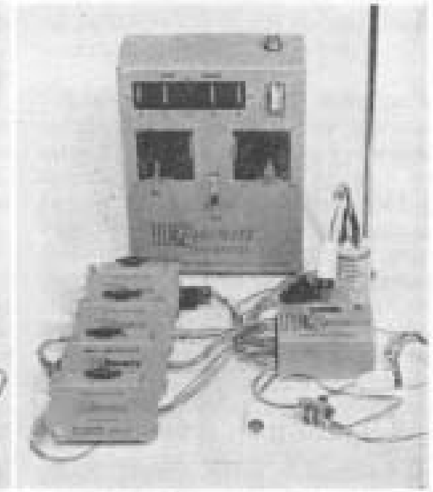
Servos are invariably of the closed loop type, and specifically designed or adapted to meet the particular equipment. The receiver is normally of the superhet type and the complete installation—receiver, servos and battery harness—is normally supplied pre-wired and requires no adjustment whatsoever. Thus fitting into a model involves only mechanical installation. About the only problems involved here are the provision of rigid but free linkages to the control surfaces so that there is minimum friction in pivot points, etc.; and the elimination of metal-to-metal sliding joints on linkages which could cause 'noise' and interference with the receiver. Mechanical installation requirements are somewhat more important than in the case of 'bang-bang' multi since whilst a relatively stiff linkage system may still work well enough with a normal 'bang-bang' or 'progressive' servo action it may cause malfunctioning when driven by a proportional servo.

The design and construction of multi-proportional transmitters and receivers—and even closed loop servos—requires specialised knowledge and experience of the problems involved and is quite beyond the scope of the average modeller to attempt. Virtually all successful proportional equipment, therefore, is of commercial origin. It is a field in which finality has yet to be reached—or even approached. Thus whilst the design and construction of conventional multi is pretty well established, proportional equipment is still (1966) in a state of development.

R.C.S. Digifive—five function fully proportional digital control system showing transmitter, receiver, five Bonner Digimite servos and battery pack, plus charging harness. Charger for both transmitter and receiver/servo power packs is built into the transmitter, so that the receiver/servo pack plugs into bottom of Tx. case for charging. Mains input to charger also connects at bottom of Tx. case. Complete system is wired ready for use.



The Dee Bee Quadruplex proportional system provides three independent proportional functions, plus one progressive function for throttle control. Receiver, servos and receiver/servo power pack are wired to servo installation board, which also carries servo amplifier circuitry.



Bonner Digimite digital proportional system provides up to eight separate proportional functions, seen here with four servos, covered by twin main control columns transmitter. Other 'auxiliary' controls operated from control panel at top of transmitter case. Trim provided for elevator, rudder and aileron main controls.

Orbit 3 + 1, analog proportional system provides three independent proportional functions with optional operation of fourth servo (+1) coupled to rudder control. Also permits uncoupling of the fourth servo at full high speed throttle position via micro-switch trigger.

Flight link proportional control system which provides proportional rudder and elevator controls, with progressive throttle control. Amplifiers for feedback servos are enclosed in large receiver case, and servos are wired direct to receiver without the use of connectors. Transmitter has single main control column with throttle control buttons on right side of case.

COMMERCIAL EQUIPMENT

CHAPTER 6

Multi-channel radio control equipment is, unfortunately, expensive—and there are no short cuts to success, or economy. Except for the relatively small numbers of individuals who have both a skill and knowledge in practical electronics *and an experience of the specific requirements of model radio control units*, the only way to success is via the use of commercial equipment. About the only savings which can be realised are in the construction of transmitters or receivers from kits of reputed design. With the modern type of printed circuit construction lending itself to the presentation of the 'wiring' in the form of a printed, pre-drilled panel this becomes largely a matter of assembly—positioning the individual components in their correct places and soldering down to the printed circuit lands. This is a relatively straightforward job for any modeller who can solder properly, although there are always chances of error which could lead to damaged components. For anyone with little or no experience of soldering, or who finds soldering difficult to carry out neatly, kit construction is likely to prove troublesome. This is particularly true of multi-channel transmitter and receiver circuits where a large number of components are involved, usually very closely spaced.

The top 'name' makes of multi radio control equipment do not offer the same equipment in kit form for the very good reason that by retaining assembly within their own workshops they can maintain their particular standard of quality control associated with all their productions. On the other hand, circuits with comparable performance are specifically produced by other manufacturers in kit form for home assembly. The smaller the difference in price between a kit and the average price of comparable ready-built equipment, the better the quality of the kit and the degree of preparation and prefabrication to ensure foolproof assembly, as a general rule.

Generalisations are, however, misleading if accepted as a basic fact. Some kit designs have a better potential performance than some ready-made equipment with the same coverage, and can achieve that performance with reasonable care and attention during assembly. On the other hand, the performance of a kit transmitter or receiver can never be better than the circuit potential, and the chances are that it will not achieve the full potential. This may be partly the fault of the kit in that some of the individual components are not as good as they could be, or more likely the quality of the workmanship in completing the job by home assembly. Over 90% of the faults in home assembly are due, directly or indirectly, to bad soldering.

Transmitters, more than receivers, lend themselves quite well to home construction, from fully prefabricated kits with high quality selected components. Design is seldom critical and components are seldom so crowded that soldering becomes a tricky operation. The job of building may be reduced to that of mere positioning and soldering of individual components if coils are pre-wound or incorporated on the printed circuit. Setting up and tuning any transmitter is also a relatively straightforward process. The overall saving may be as much as 50% of the cost of a comparable ready-built transmitter, with the kit price including a suitable case and aerial.

With receivers the saving is normally appreciably less. The heart of a conventional 'multi' receiver is the reed bank, which is an expensive item costing more than all the other components put together. Thus a receiver kit, less reed bank, may appear very moderately priced compared with a ready-made receiver, but add the cost of a *first class* reed bank and the difference will largely disappear. Thus a receiver kit may cost, say £5 to £10 (less reed bank), compared with £16 upwards for a comparable ready-made receiver (with reed bank). The best available reed bank, as an extra to the kit, may cost £8, leaving only a small possible saving. There will be no saving at all

using an inferior type of reed bank for the reliability—and thus the usefulness—of the equipment will suffer.

There is, however, the fact that a suitable basic design of tone receiver may be suitable for single-channel operation (with a relay) or may be equally well suited to accommodating a reed bank (perhaps with a change in value of one or two minor components only). This offers the chance of starting with single-channel, then adapting or converting to 4-, 6-, 8-, 10- or 12-channel operation, simply by replacing the relay with an appropriate reed bank. Operating channels can then be added in relays and standard servos; or direct operation of transistor-amplified servos.

It is undoubtedly true to say that individuals have spent far more money in aggregate, over a period, in buying the lowest possible price multi equipment, replacing, changing, etc., in an attempt to obtain reliable operation than it would have cost them to buy top-class commercial equipment in the first place. The minimum requirement for complete control with model aircraft is 8-channel equipment, which is the target to be aimed at initially. This means an 8-, 10- or even 12-channel *transmitter* as a starting point. Any 'economies' should be made on the receiver side, if necessary building up the number of operating channels progressively as finances permit. In this respect the relayless receiver offers the best proposition for, although a complete relayless outfit is more costly because of the higher price of servos with amplifiers, the initial cost of a 10-channel receiver is not very much more than one covering only 4-channels. It is, in fact, the same receiver with a 10-reed instead of a 4-reed bank.

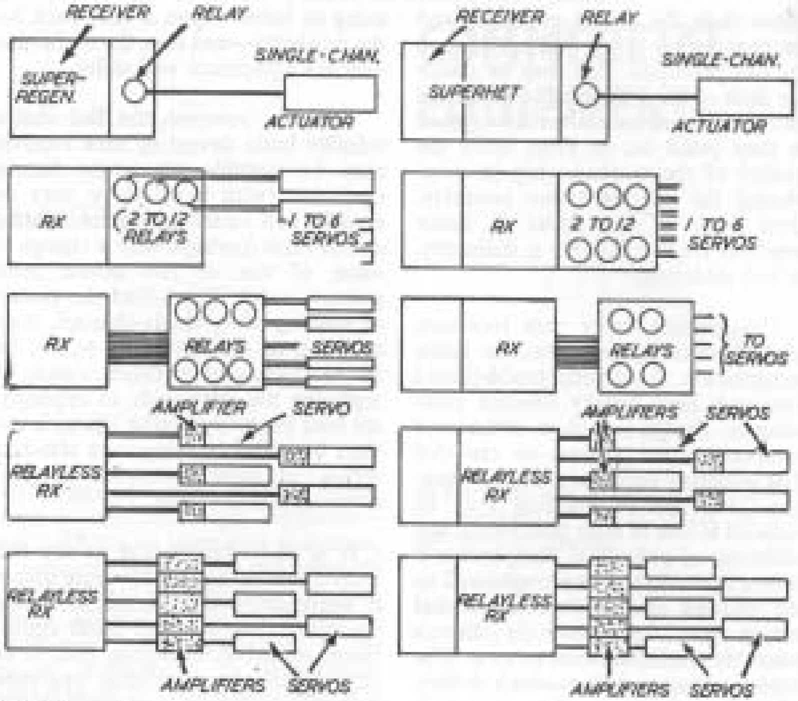


Fig. 35

Similarly, receiver requirements are identical for either relay or relayless operation. Both end at the reed bank, as far as the receiver circuit is concerned. With a relay-type receiver a series of relays (one per channel) are merely wired to the appropriate reed bank contacts and output wires for servo connections taken from the individual relay contacts. The relays are normally housed in the receiver case, but can be mounted as a separate 'bank'. With relayless operation, the servo circuit wiring is connected directly to the reed bank. Fig. 35 shows the four possible variations in 'grouping', the actual receiver part in each case being the same.

The majority of leading manufacturers do not, in fact, make relay-type reed receivers any more. The all-transistor receiver circuit is also virtually the standard, rather than the valve detector followed by transistorised amplifier stages. Again, although initial cost may be a little higher, the all-transistor receiver represents a considerable saving in the long run on battery costs, as well as battery reliability. With low voltage supplies only required for all-transistor circuits, the rechargeable DEAC nickel-cadmium accumulator has become virtually the standard form of battery, with many advantages over dry cells.

The comparative merits of valve and all-transistor transmitters have been mentioned in Chapter 2. Again the

trend is towards the adoption of the all-transistor type, although not necessarily to the eventual exclusion of the valve transmitter. The all-transistor transmitter represents no increase in performance over the valve transmitter (other than in battery demand) and the latter type has some advantages for super-regen receiver operation.

The superhet receiver is undoubtedly the 'preferred' type because of its comparative freedom from interference. However, it must inevitably be more costly than its super-regen counterpart and so both types will almost certainly remain in parallel production. Both, too, are capable of comparable performance—except as regards immunity from interference—and choice is largely dictated by depth of pocket. It would be better to 'save' on receiver cost by buying a super-regen type and spend the extra money on first class servos rather than buy a superhet receiver and cut down total cost by buying inferior servos.

With servos there is no answer but that of buying commercial units—and those of reputable make or reputation. Money spent on a 'questionable' servo, even though it may seem a bargain in price, is money wasted. More than that, it can result in expensive damage to other equipment carried in the model if it fails to operate consistently.

About the only possible saving here is with regard to servo amplifiers, necessary for use with relayless receivers. These are comparatively simple circuits and there are several excellent prefabricated kits for assembling suitable servo amplifiers to save a pound or so compared with the cost of the same servo bought with amplifier ready installed. Very little skill is needed to assemble and connect up these circuits successfully. However, bear in mind that the potential saving can disappear if one of a set of four or five servo amplifiers is ruined during assembly and has to be replaced.

As a general guide, typical cost breakdowns of multi-channel equipment are given in the accompanying tables. These data apply to conventional 'bang-bang' multi control systems and the basic requirements are irreducible—i.e. there are no cheaper ways of arranging the system, such as by 'doubling up' to save a servo, or using inexpensive single-channel actuators—without considerably reducing either the efficiency or reliability of the system.

Requirements, in terms of number of channels needed, are dealt with in detail in Chapter 7 (for Aircraft) and Chapter 9 (for Boats), where it will be seen that the *advantages* of multi-channel radio start from 2-channel, up.

Fully proportional radio control is an entirely different proposition and here commercial equipment is supplied as complete equipment embracing transmitter, receiver and matched proportional servos, usually pre-tuned and pre-wired. Services covered are normally the same—proportional control of rudder, elevators, ailerons, together with motor speed control (progressive or, again, fully proportional) and trim controls (usually for elevators and ailerons). The choice is thus restricted to different makes of complete outfits, with prices ranging from about £180 upwards for conventional quadruple-proportional systems.

TABLE I. TYPICAL COSTS OF REED-TYPE 'MULTI' EQUIPMENT (1964)

Item	*British*	*American (price in U.K.)*
Transmitters (Valve)		
4-channel	—	£25
6-channel	—	£45–£50
8-channel	—	£50–£55
10-channel	—	£55–£60
Transmitters (All-transistor)		
4-channel	£18–£25	£30–£32
6-channel	£25–£30	£35–£40
8-channel	£30–£35	£50–£55
10-channel	£35–£40	£55–£60
12-channel	£38–£42	£60–£65
Super-regen Receivers Valve—Transistor and Relay Type		
4-channel	—	£30
6-channel	—	£50–£55
8-channel	—	£55–£60
10-channel	—	£60–£70
All-transistor (Relayless)		
6-channel	—	£30–£33
8-channel	—	£32–£35
10-channel	£12–£16	£35–£40
12-channel	£15–£25	£37–£42
Superhet Receivers (All-transistor, Relayless)		
4-channel	—	£25–£30
6-channel	—	£30–£33
8-channel	£25–£28	£33–£38
10-channel	£28–£30	£38–£43
12-channel	£28–£32	£40–£50
Servo (For Relay Operation)	£4–£5	£5–£5 10s.
Servo (For Relayless Operation)		
Self-neutralising	£7–£10	£11
Trim	£7–£9	£10

TABLE II. APPROXIMATE COST OF TONE-FILTER 'MULTI' EQUIPMENT

Item	*British*	*German (price in U.K.)*
Transmitters		
2-channel		£20–£22
3-channel		£35–£40
4-channel		£34–£40
6-channel		£40–£45
8-channel		£42–£45
9-channel		£60–£65
Super-regen Receivers	none manufactured (1965)	
2-channel		£18–£20
3-channel		£22–£25
4-channel		£27–£30
6-channel		£35–£40
8-channel		£45–£50
9-channel		£48–£55
Superhet Receiver Approximate *Additional* Cost to Above		£15

RADIO CONTROL FREQUENCIES AROUND THE WORLD

Country	*Frequencies (Mc/s)*						
1 U.S.A.		26·995, 27·045, 27·095, 27·145, 27·195, 27·255					465
2 England		26·96–27·28					459 ±½
3 Germany	13·6	27		40			
4 Switzerland	13·56	26·965–27·195		40·68			433·2 434·6
5 France		27·120			72	144	
6 Belgium		26·96–27·24	32·0–32·5		72·0–72·5		
7 Sweden		27					
8 Holland		27·095, 27·105, 27·115, 27·125, 27·135, 27·145 ±0·005%				144–146	
9 Italy		27					
10 Czech'vakia		27·120		40·68		120	
11 Hungary			28–29·75			144–146	
12 Poland		27·12 ±0·05					
13 Finland		27·12 ±0·6%					
14 Denmark		27					
15 Norway		27					
16 Russia		27					
17 Turkey		27·12		40·68			

AIRCRAFT SYSTEMS

CHAPTER 7

The *primary* flying controls in order of importance are: rudder, elevators, ailerons. *Secondary* controls which increase the scope of manoeuvrability or the ease of maintaining control, again in order of importance, are: engine speed, elevator trim and aileron (or rudder) trim. Primary controls are those required *all* the time during flight. Secondary controls are those employed to alter a *trim* condition and are considerably less powerful in effect and less critical than the main flying controls. In addition one or more *auxiliary* controls may also be incorporated in the complete systems. These are, basically, secondary controls such as nosewheel steering, wheel brakes, flaps which are required and employed only on specific, and limited, occasions.

With conventional 'multi' systems the primary controls are always self-neutralising (i.e. return to neutral control position on release of signal), with 'bang-bang' action. Secondary controls are always progressive, i.e. 'inched' to the position required.

Each separate control is operated via two channels, thus for complete coverage of primary and secondary controls 12 channels in all are needed, which is virtually the practical limit for reed equipment. Auxiliary controls, if added, are then usually worked by mechanical linkage paralleled to an existing actuator.

Thus, for example, nosewheel steering can be accomplished by the rudder servo, the one servo providing both control duties. Similarly, wheel brakes would normally be operated off one position of the elevator servo or elevator trim servo by mechanical linkage. This eliminates the need for having to employ more radio channels and at the same time links the auxiliary service to a logical primary control.

The need for *secondary* and, in particular, *auxiliary* controls may not be immediately apparent. Certainly one can perform a full range of manoeuvres, and maintain complete control, without elevator or aileron trim (and the latter is largely regarded as unnecessary, anyway). However,

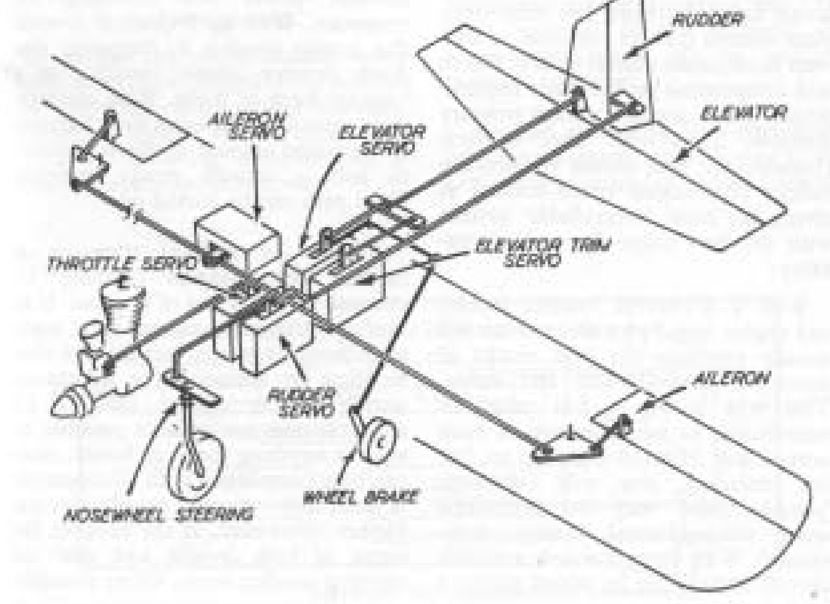
engine speed is a most important control and virtually indispensable. With a limited number of control channels available it becomes more important than ailerons—see later.

The auxiliary controls covering steering and wheel brakes are mainly useful from a 'contest' point of view where ground handling characteristics are important. They contribute nothing to flying performance, but since they can be rigged without requiring additional channels (or separate servos) they are usually worth having.

This comment applies particularly to wheel brakes where the model is fitted with a tricycle undercarriage and operated from a relatively smooth landing strip, such as a runway. Even at 'low' throttle thrust may well be sufficient after landing to keep the model rolling indefinitely, until it eventually runs into some obstruction. Wheelbrakes in such a case are invaluable to bring the model to a standstill and steering equally useful to assist in taxying. They can be linked to a movement not normally required when taxying—e.g. full down elevator movement (8-channel) or full down elevator trim (10-channel) with a tricycle undercarriage. (Fig. 36.)

Standard multi-channel radio is normally produced in 3-channel (tone filter only), 4-, 6-, 8-, 10- and 12-channel versions, the cost increasing with the number of channels. The 3-, 4- and 6-channel units can only offer *less* than complete control and are really applicable only to model designs which have a certain degree of inherent

Fig. 36



stability, and in this respect are similar to single-channel R/C model designs. The 8-, 10- and 12-channel units are suitable for specialised 'multi' aircraft designs. The one exception to this basic rule is that *pylon racers* can be controlled successfully on a 6-channel system by dispensing with rudder control and using ailerons, elevator (or elevator trim) and engine speed controls. Satisfactory, if not complete control can also be obtained with 6-channel systems on suitable *low wing* model designs, again omitting rudder control. Models of this type represent the least expensive proposition for 'multi' flying and can have a good, if not comprehensive performance.

With all other types of R/C models the rudder is the one indispensable control although with a complete control system (eight channels or more), it is virtually required only for take-off and possibly during the landing approach and hardly used at all during actual flight. Anything less than complete control (i.e. six channels or less) *must* incorporate rudder as first choice and compromise on the other requirements which are not always primary controls. Thus with three or four channels the best choice is normally rudder plus engine speed control as giving the most 'controllable' system with the best scope for manoeuvrability.

With a 6-channel system, rudder and engine speed plus elevator control usually produces the best results in terms of controllability and scope. This will enable a full range of manoeuvres to be performed in both normal and inverted flight up to, but not including, true rolls (although 'pseudo rolls' may be performed using single-channel control techniques). With eight channels available aileron control can be added giving a completely controllable and fully manoeuvrable model. The only limitations on manoeuvrability are then due to limitations in the *aircraft* design, and/or lack of engine power. As regards the latter point, the more complete the control system the more necessary it becomes to have plenty of engine power available to take advantage of the scope for manoeuvring. Thus it is better to have an over-powered rather than an under-powered model, particularly as with engine speed control it is not necessary to fly at full throttle all the time.

Any additions to the normal 8-channel system—rudder, elevators, engine speed and ailerons—are more in the nature of refinements than *necessary* controls. Elevator trim is highly desirable as promoting smoother flying by enabling the model to be trimmed out for a particular flight path in the pitching plane. For example, to hold a model in inverted flight a certain amount of 'down' elevator power will normally be necessary. With an 8-channel system this is only possible by 'blipping' the down elevator control, resulting in a 'steppy' form of flight. With elevator trim control via the extra two channels the required amount of down elevator to hold a smooth steady inverted flight path can be inched on.

Aileron (or rudder) trim via a further two channels (making 12 channels in all) is less of a virtue. It is useful to trim out a natural turn, such as induced by warps, but this can also be done by adjusting the sidethrust setting of the engine. In fact 12 channels does not make it possible to achieve anything more, or better, than can be accomplished with 10 channels. It does, however, offer possibilities for further refinement, at the expense (in terms of both weight and cost) of carrying another servo. Other possible

uses, alternative to aileron or rudder trim are for retracting and lowering the undercarriage, or operating flaps, as offering refinements in *flying* controls; or for 'novelty' services, such as 'bomb' or parachute release gear, controlling a camera mounted in the model, and so on.

The only justifiable reason for accepting less than eight channels for 'multi' operation is one of cost. Equally, it is not possible to extend the service coverage of a limited number of channels by using single channels to operate a particular control without losing much of the advantage of 'multi'. It may be possible, in theory, to allocate, say, a 6-channel unit to operate:

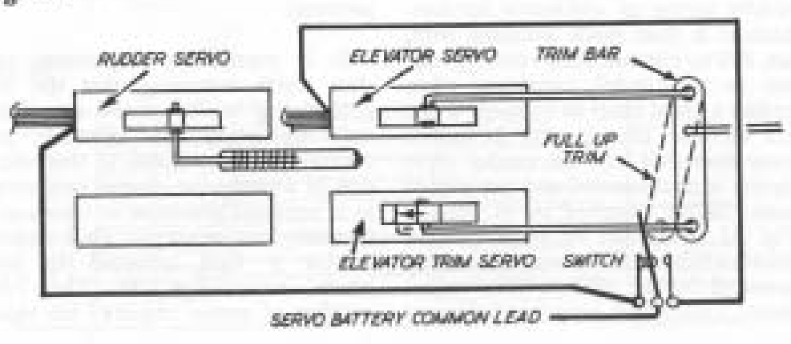
(i) rudder via two channels,
(ii) elevators via two channels,
(iii) ailerons via one channel in typical 'single-channel' sequence,
(iv) engine speed via one channel, in the same manner.

In practice, the 'single-channel' operation of services (iii) and (iv) is unlikely to prove satisfactory; and the same comment applies to any other combination involving departure of 2-channel operation per service.

With a 6-channel system there is, however, the possibility of 'coupling' rudder and ailerons so that both are operated together by the same (rudder) signal. This can be done simply by wiring the aileron and rudder servos in parallel, provided the circuit is capable of supplying the necessary current to operate both servos together (i.e. 'coupling' in this manner is usually best with a relay-type receiver using a separate servo battery which can be of sufficient capacity to withstand the higher current drain for paralleled operation.) This, of course, is only a compromise solution for simultaneous aileron and rudder movement is not always desirable. With 'full house' multi, in fact, only the ailerons are normally used for turns and about the only application of rudder during normal manoeuvres would be to induce a spin following a stall (and even that may be done on ailerons only). Thus a coupled aileron and rudder system may prove an embarrassment, or give over-control or even 'crossed' control response at times, particularly if the rudder power is excessive.

Another alternative for 'extending' a 6-channel system would appear to be using aileron *instead* of rudder control,

Fig. 37



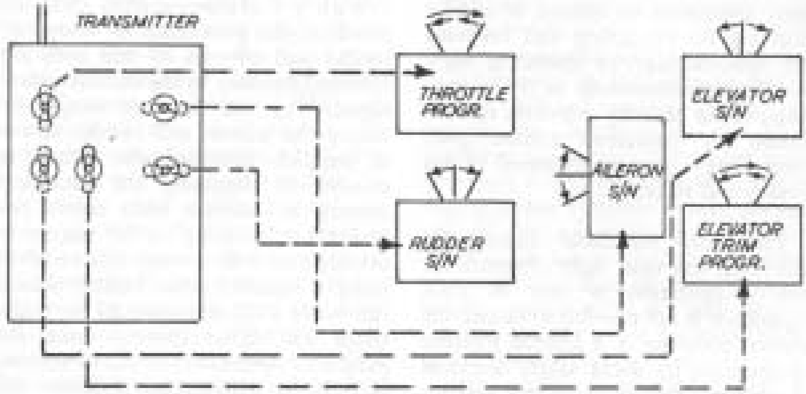


Fig. 38

but again this seldom works out satisfactorily in practice, except, as previously mentioned, in the case of pylon racers. Virtually all the possible combinations for 'improving' restricted service 'multi' have been tried and found lacking in one or more respects. The recommendations given in Table I are based on sound practice and selected as giving the best overall performance (controllability and manoeuvrability) with the number of channels specified.

With an 8-channel system the possibility of extending the control service coverage does become practical, e.g. by wiring up the aileron and rudder servos as *alternative* services. Rudder is then made available with, say, full up elevator trim—corresponding to the 'trim' condition when rudder is most likely to be used. When the elevator trim control is moved away from full 'up' the rudder servo circuit is disconnected and the aileron servo circuit switched in its place—Fig. 37. This can be done using a microswitch with two sets of contacts operated by the elevator trim movement. Thus a 'full house' complement of controls can be provided with only eight channels—elevator, elevator trim and engine speed being operated by six of the available channels; and rudder *or* ailerons by the remaining two channels, depending on the position of the elevator trim control. This is a particularly useful adaption of commercial tone filter radio where the possible number of channels is limited to a maximum of eight. With a reed receiver normal 10-channel operation would be a logical choice by conversion of existing 8-channel equipment if necessary (e.g. adding two more tone channels to the transmitter and replacing an eight reed with a 10 reed bank in the receiver).

It is particularly important, and thus worth repeating, that the full potential of 'multi' control is realised only by using *two* channels per control service required so that selection of a particular control movement in a required direction is direct and (virtually) instantaneous. Each control service is then powered by one 'multi' servo—Fig. 38. Thus the number of servos required are equal

to the number of primary and secondary controls to be operated; and the number of channels provided by the transmitter-receiver combination must be equal to twice the number of primary and secondary controls.

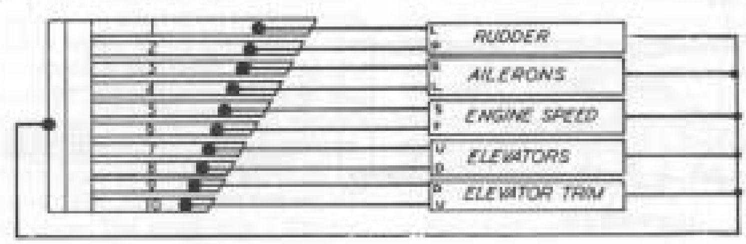
As far as grouping of controls for simultaneous operation is concerned, some compromise is usually necessary according to the number of simultaneous groups available. With reed receivers simultaneous operation is normally confined to two groups of four, five or six channels each, for 8-, 10- and 12-channel receivers, respectively. With tone filter receivers there may be two or three simultaneous groups, depending on the design of the transmitter.

The main requirement, as far as flying is concerned, is for simultaneous operation of ailerons and elevator, which would thus be allocated to separate groups. A trim control would never be required at the same time as the same main control, so can be placed in the same group (e.g. elevator trim in the same group as elevator control). Engine speed control would more likely be needed simultaneously with elevators than ailerons or rudder, so would be grouped with the latter. If necessary to split, then 'fast' engine would normally be associated with elevator and 'slow' engine with ailerons (e.g. on a 10-channel system). Typical recommendations are summarised in Table I.

With a reed receiver there is also the possibility of inter-action between adjacent reeds. Thus whilst allocation of the reeds is normally based on adjacent pairs, for convenience, the distribution of the pairs would aim at reducing the effect of possible accidental 'simultaneous' operation or interference with simultaneous operation. Typical allocation schemes are shown in Fig. 39. Thus whilst simultaneous operation of two adjacent reeds in the middle of the bank may possibly cause the receiver to chatter this likelihood is restricted to a combination unlikely to be called for in practice—e.g. simultaneous operation of ailerons and engine speed.

Power for *auxiliary* control operation is normally derived from mechanical linkage to an appropriate servo governing one of the primary controls, or even directly to a control surface. Thus in the case of a steerable tailwheel, steering can be accomplished by linking the tailwheel direct to the rudder—Fig. 40. This diagram also shows how braking can be applied to the tailwheel, operated from mechanical linkage connected to the elevator so that 'up' elevator position also gives 'brake on'. The fact that 'brake on' is also applied during every 'up' elevator movement during flight is immaterial

Fig. 39



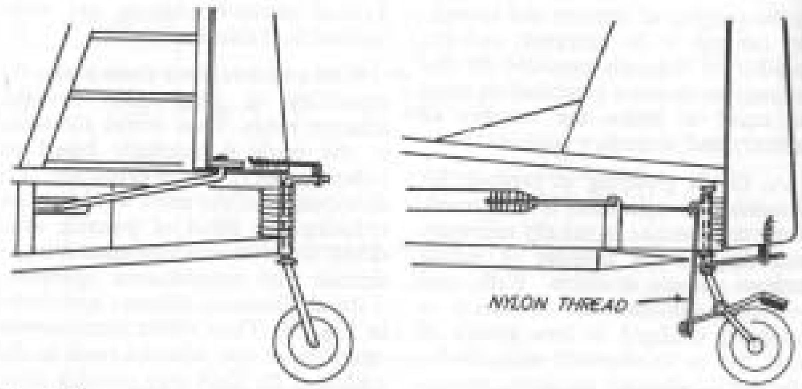


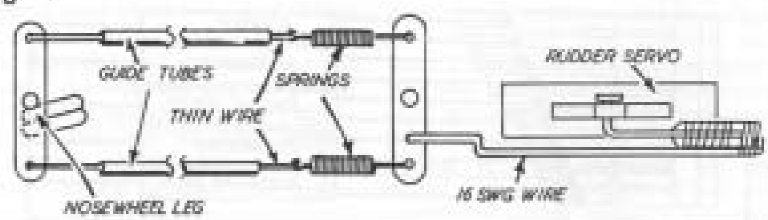
Fig. 40

as it does not affect the working of the flying control, provided the servo is powerful enough for the job and the brake linkage movement cannot jam.

In the case of nosewheel steering on a tricycle undercarriage, the steering linkage is normally taken off the rudder servo—Fig. 41. To relieve this servo of shock loads transmitted through the nosewheel unit running over the ground a spring or springs may be incorporated in each push-pull link, although this is not invariably done. Braking, applied to the main wheels in a tricycle undercarriage system, would be taken off the elevator servo movement, pulling pads into contact with the wheel tyres as shown in Fig. 42, or providing the necessary 'pull' action to operate hub brakes on specially designed wheels. Again some flexibility in the 'pull' linkage is desirable in order to prevent the full 'on' movement of the brakes acting as a rigid stop for the full movement of the elevator servo. This may be given by using an extensible spring in the 'pull' linkage or an 'elastic' pull line, such as thin nylon cord.

Aircraft design largely falls into two distinct types. Those intended for a limited range of controls—i.e. less than 8-channel operation—normally follow a basic layout similar to single-channel R/C aircraft with a preference for high wing or shoulder-wing position and a reasonable dihedral angle to promote a certain reserve of inherent stability. The more advanced aerobatic models intended for 'full house' multi generally

Fig. 41



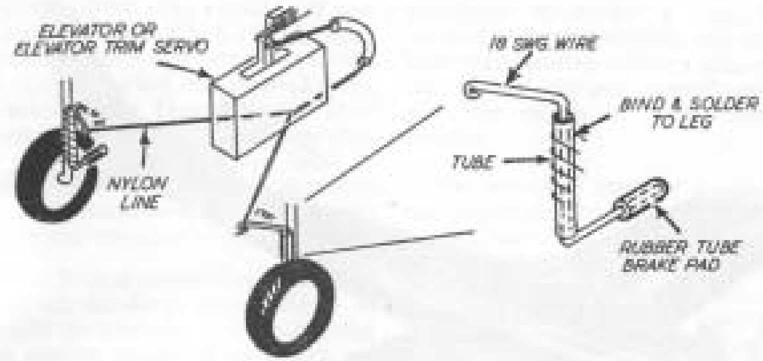


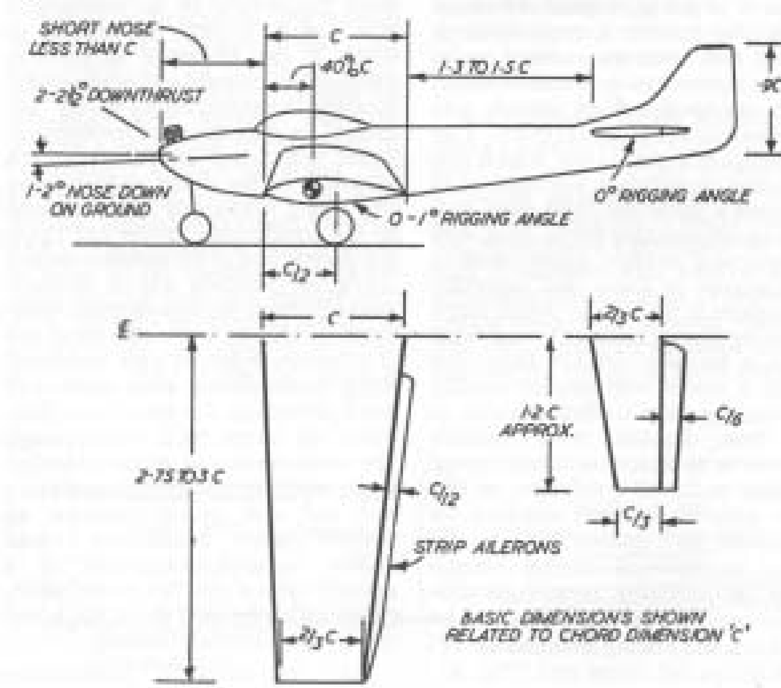
Fig. 42

favour the low wing layout as being capable of 'zeroing out' in trim—i.e. the stability margin is virtually reduced to zero so that the model will tend to remain in a particular flight path to which it is put by control movement when that control is neutralised. A model with inherent stability under similar circumstances would 'recover' to its one specific flight attitude with neutral control positions. The advantage of a 'zeroed out' trim is that continual correction is not required to maintain a particular flight path, thus making for smoother flying. Also, with no reserve of stability, displacement in manoeuvres is faster and smoother since there is no built-in design factor opposing displacement. On the other hand, it becomes virtually impossible to fly a model with neutral stability without complete control available all the time. Equally, it is virtually impossible to achieve complete neutral stability under all conditions, so that trim controls are still required for smoothest performance. This is also where proportional control systems score in providing continuous proportional control movement, as required, and placing less onus on aircraft design and initial trim. (Fig. 43.)

'Multi' aircraft design, as such, has become largely standardised after a period of 'trial and error' development. With 'full house' control complement, virtually *any* model layout can be flown successfully by an experienced pilot and it is only the manner in which it can be made to perform standard manoeuvres and/or its general handling characteristics which are affected by differences in aerodynamic layout and detail. In particular, the behaviour of the model when turning and rolling will largely be determined by the aerodynamic layout and shape and proportions of the movable control surfaces. Models which deviate markedly from the conventional 'aerobatic' layout may well suffer some loss of manoeuvrability, or have 'awkward' flying characteristics. Even quite small detail differences can have their effect. Thus the swept back rudder hinge line characteristic of modern designs is not merely for a matter of appearance and can well prove beneficial on 'limited' multi installations where rudder is used continually as a primary control (on 'full house' multi, rudder is hardly used at all, but is still retained as a primary control).

For best aerobatic performance

Fig. 43



relatively thick wing sections are now normally favoured (e.g. 18%), symmetrical or near-symmetrical in profile to equalise normal and inverted flying characteristics. The particular aerodynamic advantage of the thicker wing is that flying speed is less liable to rapid acceleration and decelerations through manoeuvres, making the model easier and smoother to fly.

The critical manoeuvre as regards inherent handling characteristics is usually the true spin. It is possible that the stability margin of the design has been so reduced that complete instability is produced in a spin, making recovery very delayed, or even impossible even although all control movements are available. On the other hand a number of modern high-performance low wing aerobatic designs are particularly reluctant to spin with normal control movement. In such cases it may be necessary to provide for additional up elevator movement to initiate a spin, this 'override' movement being only available when wanting to start a spin—e.g. normal 'up' elevator control applied with the engine in 'slow' throttle position.

The necessary override movement can be provided by mechanical linkage coming into effect only when full 'up' elevator is applied in the 'slow' throttle position; or, more conveniently, by arranging that with this particular combination of control signals an additional switching circuit is brought into effect on the elevator servo board allowing the servo motor to override its normal 'stop' position and produce a longer than usual movement of the output arm. This entails a special design of servo switching board incorporating 'overdrive' which, typically, gives about twice the normal 'up' elevator movement under specific conditions.

TABLE I. ALLOCATION OF CONTROL SERVICES
(USING MULTI SERVOS EXCEPT WHERE NOTED*)

	Rudder	*Elevators*	*Engine Speed*	*Ailerons*	*Elevator Trim*	*Aileron or Rudder Trim*
2 channel	1-R : 2-L (S/N)	—	—	—	—	—
3 channel	1-R : 2-L (S/N)	—	3 (Sequence)*	—	—	—
4 channel	1-R : 2-L (S/N)	—	3 and 4 (Progressive)	—	—	—
5 channel	1-R : 2-L (S/N)	3-U : 4-D (S/N)	5 (Sequence)*	—	—	—
6 channel	1-R : 2-L (S/N)	3-U : 4-D (S/N)	5 and 6 (Progressive)	—	—	—
8 channel	1-R : 2-L (S/N)	3-U : 4-D (S/N)	5 and 6 (Progressive)	7-R : 8-L (S/N)	—	—
9 channel	1-R : 2-L (S/N)	3-U : 4-D (S/N)	5 (Sequence)*	6-R : 7-L (S/N)	8-U : 9-D (Progressive)	—
10 channel	1-R : 2-L (S/N)	3-U : 4-D (S/N)	5 and 6 (Progressive)	7-R : 8-L (S/N)	9-U : 10-D (Progressive)	—
12 channel	1-R : 2-L (S/N)	3-U : 4-D (S/N)	5 and 6 (Progressive)	7-R : 8-L (S/N)	9-U : 10-D (Progressive)	11-R : 12-L (Progressive)

* Single-channel Servo.
R = Right: L = Left: S/N = Self-neutralising.

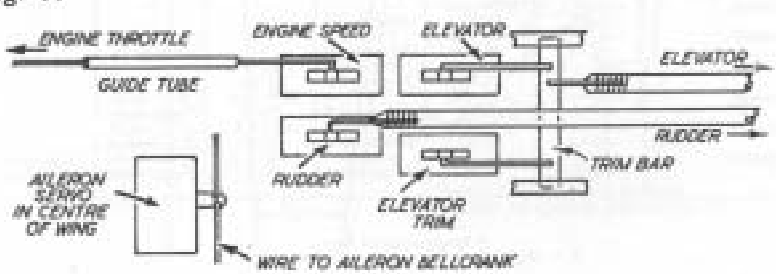
AIRCRAFT INSTALLATIONS

CHAPTER 8

All 'multi' aircraft installations are basically similar, differing only in the number of channels available, and thus the number of individual servos installed. Normal 'full house' comprises 10 channels with five servos controlling rudder, elevators, ailerons, engine throttle and elevator trim, each service controlled by its own servo. Auxiliary services, such as nosewheel steering and brakes, are mechanically linked to the rudder servo and elevator or elevator trim servo, respectively (see Chapter 7). The basic 'full house' installation shown in Figs. 36 and 44 is thus descriptive of any multi installation, merely omitting the appropriate control(s) and servo(s) where less than 10 channels is available.

The typical 'multi' servo is rectangular in shape with the casing designed to provide for flange mounting with holes in the flanges large enough to accommodate rubber grommets.—Fig. 45. It is intended to be fastened down to a rigid mount—e.g. a rigid ply tray or servo board in the fuselage, or a ply facing on the side of the fuselage—with the mounting bolts passing through the rubber grommets without making metal-to-metal contact with the case. These bolts are then tightened up enough to provide a reasonably rigid fixing, but at the same time not over-tightened so that the shock absorbing properties of the rubber grommets is destroyed. To locate the servo positively against fore and aft movement, balsa or hardwood strips may be cemented to the servo tray immediately in front and behind the servo. This is particularly effective in preventing fore and aft movement of

Fig. 44



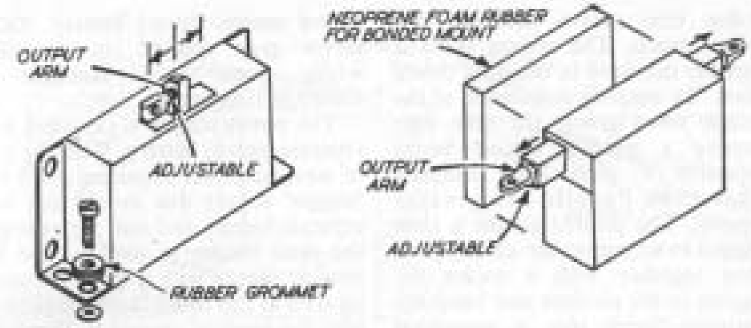


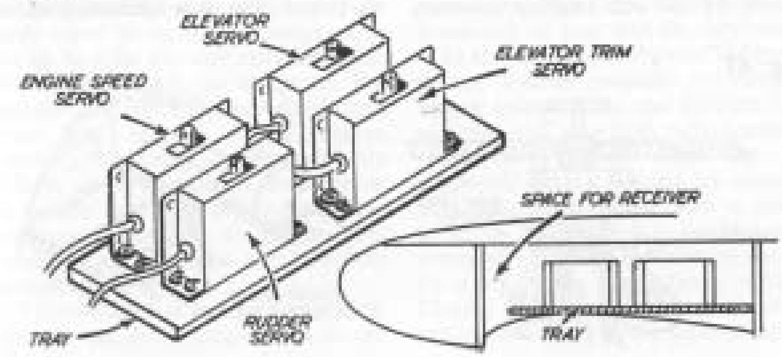
Fig. 45

the servo due to vibration with a 'soft' mounting but is by no means universally employed.

With the smaller lightweight servos, bonded mounting can be used successfully. Here the servo is glued to a rectangle of neoprene foam rubber or similar rigid foam material about ¼ in. thick and thence glued to the fuselage or servo tray. Gluing to the side of the fuselage is preferred since this gives the greatest bonded surface area. An impact adhesive is used for bonded mounting (e.g. Evo-Stik). The mounting is 'permanent', but a bonded servo can readily be removed by peeling back a corner of the rubber mount and running a little solvent such as ether into the crack so formed. This will immediately soften the adhesive, allowing the servo and its mounting pad to be peeled off. It can be refastened by gluing again as soon as the solvent has evaporated off.

Servos are normally mounted in groups on a tray (or on the fuselage sides) in the centre of the fuselage near the balance point of the model—Fig. 46. With tray mounting the whole tray can be positioned fore and aft, as required, to achieve correct balance after the servos have been mounted. The tray itself must be firmly glued and/or screwed in place so that it cannot break loose in a heavy landing. Rudder, elevator, engine throttle and

Fig. 46



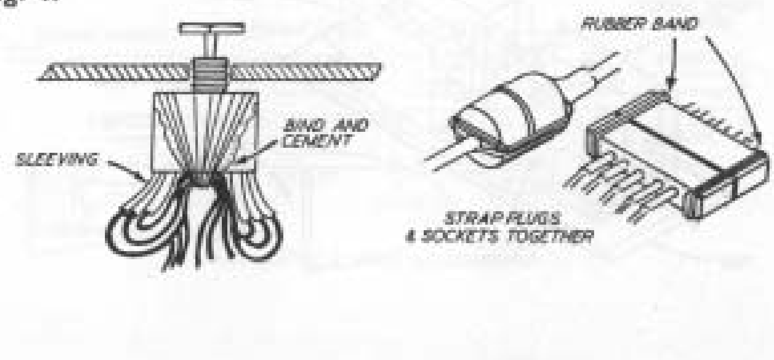
elevator trim servos comprise the fuselage group. The aileron servo is invariably mounted in the wing centre section. To simplify installation of the fuselage servo group the tray may comprise a printed circuit board (preferably a glass fibre laminate rather than Paxolin for greater strength). The printed circuit is then designed to accommodate all the servo wiring together with a socket for plugging in the receiver and batteries. A printed circuit tray is somewhat heavier than a ply tray, but does permit a neat, integrally wired installation which can be fitted or removed complete merely by coupling or uncoupling the pushrod ends.

Each individual servo has a number of wires emerging which are normally best terminated in a multi-pin plug to connect with a matching socket. All the sockets necessary to accommodate the different servo plugs can be mounted together (e.g. on the servo tray) as the power leads to these can be commoned. Many experts, however, prefer not to fasten sockets but allow the plug and socket assembly to lie freely within the fuselage. The number of individual servo wires involved varies with the design of the servo. Thus an 8-wire servo 'cable' is typical of a conventional multi servo for use with relay-type receivers, and a 6-wire cable with transistor-amplified servos for use with relayless receivers and a centre tapped battery. Other servos may operate on simplified wiring. Some typical examples are shown in Chapter 4.

The power supply is provided by a separate (servo) battery. With the type of servo amplifier requiring a 1·5 volt 'trigger' supply this should also be a separate battery and not, for example, the same battery as used for the low tension supply with a valve-transistor receiver as this could cause interference with the receiver operation. Physically this can be accommodated in a single battery with suitable tapping points.

Any switches incorporated in the circuit should be a good grade of toggle type rather than a slide type and located in a position on the side of the fuselage where they cannot be smothered with oil from the engine. Wiring runs should be kept as short as practical, but with a reasonable amount of slack at the terminal ends to avoid any pull on soldered connections. Ends should be sleeved and, where attached to a switch, a loop of slack wire should be formed in each lead and bound to the body of the switch as shown in Fig. 47. Plugs and sockets should also be held together positively with a rubber band, if possible and every precaution taken to ensure that no soldered joint is subject to any possibility of being pulled or strained under vibration by a wire being too short and tight. Any additional wiring

Fig. 47



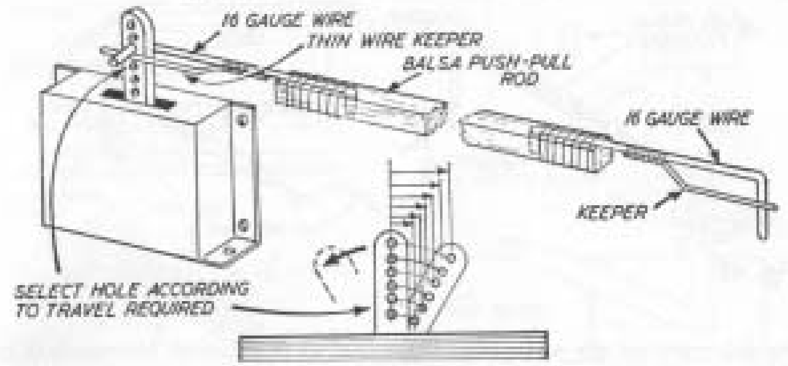


Fig. 48

required should be done with multi-strand insulated wire (e.g. 12/004 or 14/0076) and all connections to be made *soldered*, taking care to make perfect joints. Under no circumstances should twisted up or screwed (terminal) connections be used as these are very likely to failure under vibration.

All parts of the servo which are held together by screws—e.g. self-tapping screws holding the servo printed circuit switching board in place, or the cover in position—should be locked against vibration with a coating of suitable glue (e.g. an impact adhesive). It is also a wise precaution to bind the servo case with cellulose tape as a double precaution against fastenings working loose. Servos which rely on grub screw fixing for the output arm on its spindle are not reliable unless the screw locates on a flat on the spindle and is also securely locked with 'goo' (e.g. a thread locking cement). What may appear a perfectly reliable set up on a bench can be prone to failure in actual use unless every precaution is taken to ensure that vibration cannot cause any loosening of fastenings, etc.

The mechanical linkage required to connect the servo output arm to the appropriate control surface is comparatively straightforward. A rigid push rod is invariably used to connect the rudder or elevator servo to its respective control surface, comprising a length of hard balsa of adequate section ($\frac{1}{4}$ in. sq. on models of about 48 in. span; $\frac{3}{8}$ in. sq. on larger models), with wire end fittings bound in place—Fig. 48. To ensure that the push rod end fittings cannot jump out of place it is essential that they be fitted with keepers, as shown. The soft wire binding holding the keeper wire is sometimes omitted, but is always best used as an additional precaution. Another important point is that the wire end fittings *must* be securely and rigidly bound to the balsa rod, with the ends turned into the balsa to prevent any possibility of fore and aft movement.

In the case of the throttle linkage it is not usually possible to carry a square section balsa rod forward and so a thin, stiff wire push rod is normally employed—Fig. 49. This can be supported against bowing by running in a length of tubing with a fairly generous clearance—e.g. an 18 s.w.g. piano wire push rod should be run in 16 s.w.g. (bore size) brass tubing. Ideally, the amount of movement of the throttle arm should correspond to

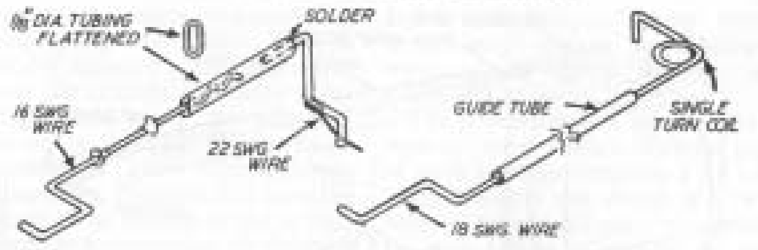


Fig. 49

the full travel of the servo arm, but differences in the two movements can be accommodated by adopting suitable 'lever arm' lengths at each end. There is, however, the point that the actual throttle arm movement may be varied by adjustment of the throttle stop. Any difference in movement can be accommodated by allowing a suitable unsupported length of the operating wire to flex or, alternatively, by fitting a compensating device in the operating wire length. For flexing action, which is by far the simplest arrangement, a fairly thin wire is required, or alternatively Bowden cable can be used, provided the tubing is carried well forward so that the cable cannot bow excessively on the 'push' action. Operating loads on the throttle movement are normally very light in any case.

Coupling up the elevator trim servo is basically an exercise in geometry. Two different methods are shown in Fig. 50. The principle is the same in each case, terminating both the elevator servo link and the elevator trim servo link on a bar or lever and taking the link to the elevator itself from an intermediate position on the bar. Movement of the *elevator* servo then causes the bar to pivot about the elevator trim link point, the elevator push rod being positioned a suitable distance from this point to provide the necessary throw for full elevator movement required. Movement of the *elevator trim* servo pivots the bar about the elevator servo link. The elevator push rod being much closer to this point is then operated with less leverage to produce a smaller 'trim' movement. Equally, the same elevator movement is achieved via the elevator servo regardless of the position of the bar as moved by the 'trim' servo.

To accommodate the necessary movements, the bar itself must be freely floating, a simple solution being to arrange that each end is guided but free to slide in grooves. A neater form of linkage is shown in the second diagram, accommodating the linkage down the side of the servos. This system dispenses with the need for guides.

In all cases the actual amount of control movement produced is a function of the servo output arm travel and the effective length of the control horn (or bar with elevator/elevator trim linkage). It is a simple matter to adjust the amount of control movement by selecting different positions for the push rod at the control horn end. The amount of movement required will vary according to the model design and engine power used, but typical recommendations are summarised in Table I. Note in particular how a very small movement is required for elevator trim. Since this is a 'progressive'

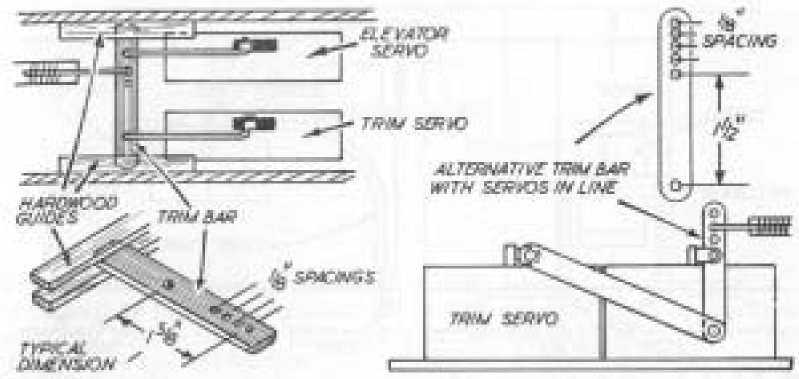


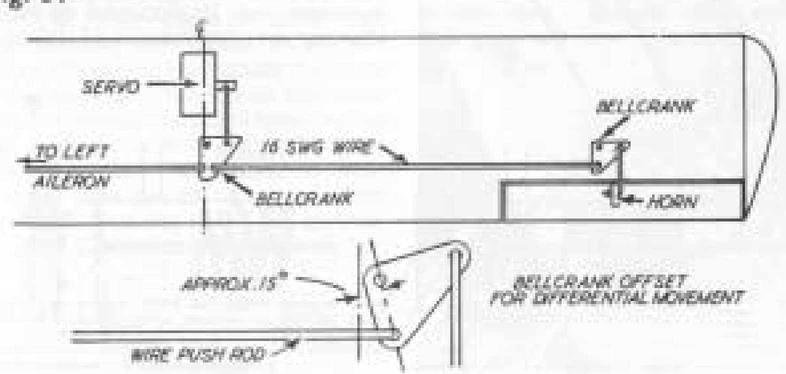
Fig. 50

control, and thus its position can only be observed by the effect it has on the model's performance, an excessive movement should never be used. It is generally best to adjust, as necessary, so that full 'down' trim corresponds to the amount of down elevator necessary to maintain level inverted flight. It is then only necessary to hold on down elevator trim for about a second on going inverted to ensure correct trim, without having to 'feel' for the required trim.

With the aileron servo mounted in the centre section of the wing and the necessity of accommodating the push rods within the wing profile, a rigid wire linkage is normally employed—Fig. 51. This can be supported against bowing at intervals, as necessary, by small bushings. The push-pull movement of the servo is finally translated into aileron movement via a bellcrank and a short link connecting to the aileron horn at each end. By offsetting the bellcrank, as shown, differential aileron movement can be achieved.

Differential movement simply means that the 'up' travel of the aileron is greater than the 'down' movement.

Fig. 51



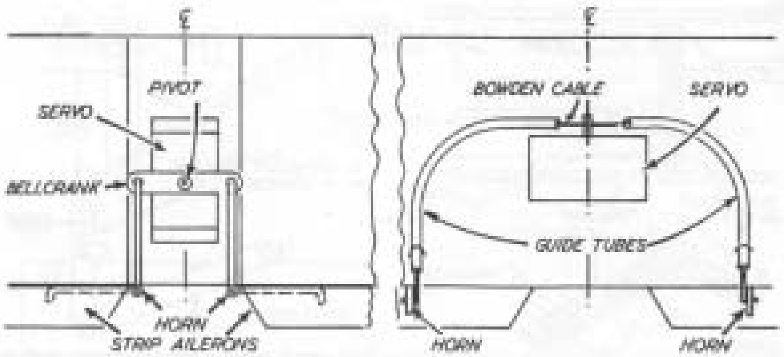
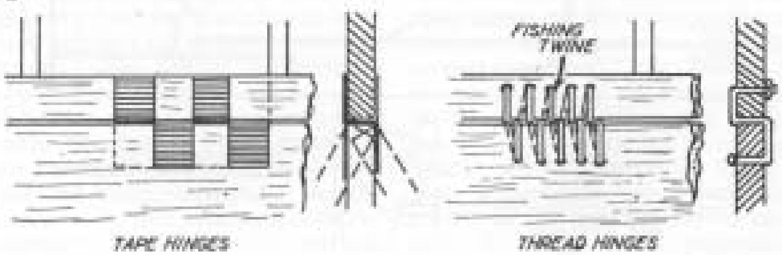


Fig. 52

This is desirable since whilst a downward displaced aileron increases the wing lift on that side it also increases the drag. Thus whilst the increased lift induces a roll or bank, the extra drag tends to oppose this motion by yawing the model in the opposite direction. Also the banking or rolling effect of large downward movement is not much greater than that achieved with only moderate displacement whilst the yawing effect increases directly with displacement. Thus a differential movement giving about 15–20 degrees down and 25–30 degrees up is a much more effective control than one with equal aileron movements up and down. The actual power of the ailerons is then decided by their area, 5% of the wing area being a typical figure for producing slow, smooth rolls with about 30 degrees up and 20 degrees down movement, although more powerful ailerons may be used on highly aerobatic models. Optimum proportions (and movements) are dependent to a large extent on the overall design of the aircraft.

Strip ailerons are now more favoured than conventional inset ailerons for aerobatic models, the aileron being of narrow chord and hinged directly to the trailing edge of the wing—Fig. 52. Typical area for a strip aileron is 4–5% of the wing area (each aileron) with a movement of 20 degrees up and 20 degrees down. Equal up and down movement may be employed on strip ailerons, for convenience of linkage design, when adverse yawing effects can be reduced by limiting the amount of movement and by tapering the chord of the aileron towards the tips.

Fig. 53



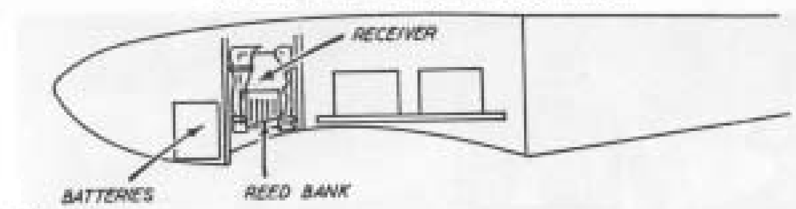


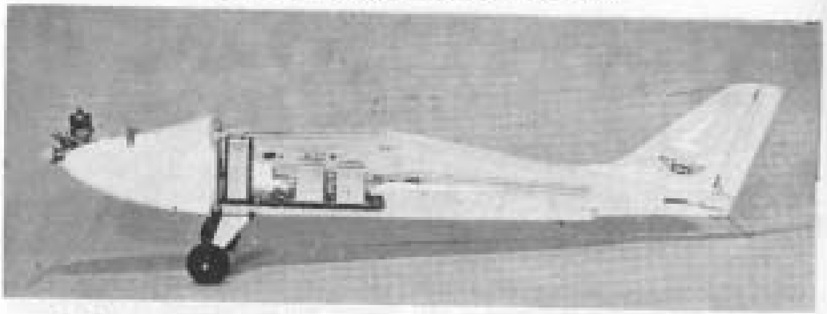
Fig. 54

Apart from representing a simpler constructional job (strip ailerons are cut from sheet balsa and can be hinged to the wing after covering) linkage lengths can be reduced to a minimum since they can be attached to the inboard ends of each aileron, near the servo. A straightforward mechanical linkage system can be used, or the push-pull action of the servo transferred directly to each aileron horn via a short length of Bowden cable running in a curved brass tube. The latter is particularly suitable for use on smaller models. Both types of linkage are illustrated in Fig. 52.

The essential feature of any control linkage is that it should act freely without binding or distortion, with a minimum of slack movement. Where bellcranks are employed these are best made of nylon—e.g. a cut down small size control line model bellcrank—since this material is virtually free from 'bearing wear'. Aluminium bellcranks tend to develop elongated holes leading to control surface chatter due to excessive slack movement. If bellcranks have to be cut from sheet material $\frac{1}{16}$ in. Paxolin should be used. This is also suitable for the trim bar.

The freedom of movement of a control will also depend to some extent on the type of hinge employed. Tape hinges, control line style, are still widely used, but thread hinges are generally to be preferred—see Fig. 53. The type of hinge is not all that important, provided it operates freely without 'chatter' between the two surfaces, and is long lasting. Hinges which have become weak or loosened need immediate replacement. Other parts of the control linkage also need frequent inspection to check that all is well and that anchorages have not become loosened—e.g. particularly

Right: six channel servo installation, showing three Bonner Duramite servos mounted on plywood plate. Throttle servo at left, elevator servo central and rudder servo on right. Linkage on front of servos couples rudder servo to ailerons for C.A.R. system.



Installation of C & L Developments Servamite installation pack for 10 channel operation. Receiver is fitted ahead of servos. Aileron servo in wing plugs into servo board circuit.

control horns and bellcrank pivots. Properly installed however, a well designed linkage system should give long, trouble-free service. It is as well to spend time on getting the linkage right in the first place and eliminating all initial or potential sources of binding, etc.

The modern relayless receiver represents very little problem for mounting and is largely shock and vibration proof except for the reed bank. Adequate shock protection is normally provided by wrapping the receiver round with $\frac{1}{4}$ in. or $\frac{1}{2}$ in. thick foam rubber (or preferably processed 'horse-hair' type insulation) held in place with rubber bands. The receiver is then simply placed in a suitable compartment in the fuselage, usually forward of the servo tray—Fig. 54. The receiver should be quite a loose fit in the compartment made to take it when spare space can be filled with foam rubber again, fairly loosely packed but tight enough to prevent the receiver from moving about.

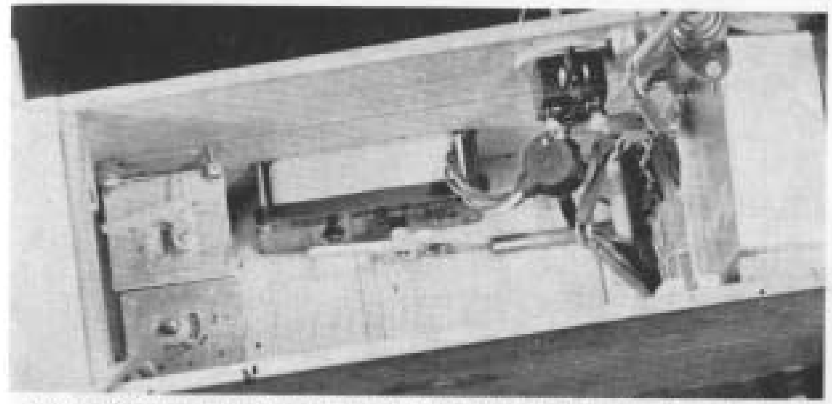
The insulation will still not isolate the reed bank completely from vibration, but any stray vibration effects still reaching it can be minimised by locating the receiver in such an attitude that the reeds in the reed bank hang vertically downwards. This places them in a position where they are least likely to be affected by vibration. Similar considerations apply to a relay type receiver. A vertical position, with the relay armatures and reed bank hanging downwards should produce the least effect from vibration. With tone filter receivers the mounting position is unimportant, unless the receiver is a relay type when the same considerations apply.

TABLE 1. TYPICAL CONTROL SURFACE DATA

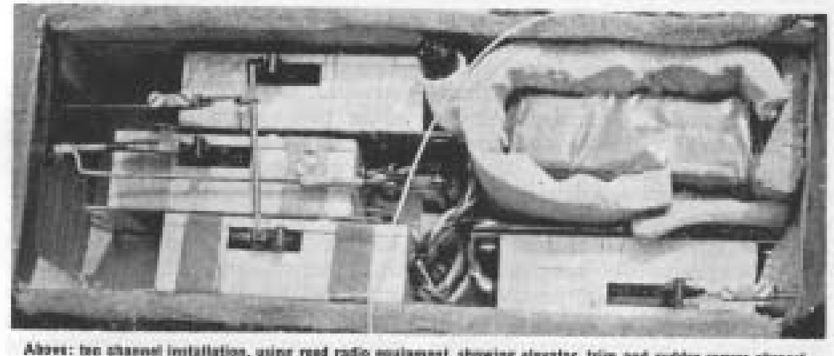
(SEE ALSO FIG. 43)

Control Surface	*Area % Wing Area*	*Movement*
Rudder	2–3	30° Right; 30° Left
Elevators	4–5	Up 10°; Down 15°
Elevator trim	—	Up 2°; Down 2°
Ailerons:		
Conventional	8% (each aileron)	Up 30°; Down 20°
Strip type	4–5% (each aileron)	Up 20°; Down 20°

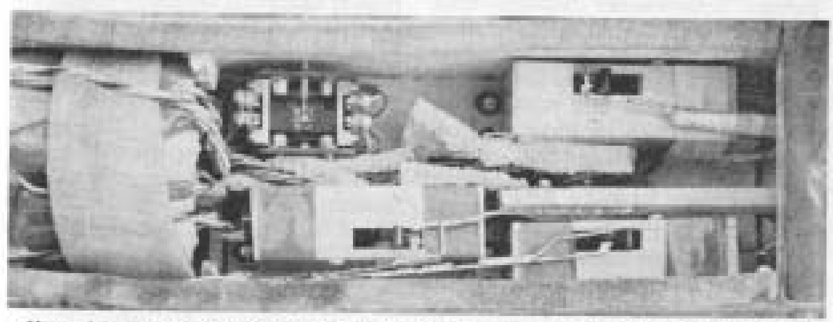
Note: The amount of control movement required will depend a lot on the type and weight of model, the power, and also trim. Provision is usually made to adjust the movement as necessary—e.g. by having alternative holes in the control horn for positioning the push-rod end and thus varying the length of the effective lever arm.



Above: five channel multi installation showing two Duo-Matic centrifugal clutch servos at rear of equipment compartment for rudder and elevator controls. One channel Unimatic servo operates throttle control. Receiver, with separate relay pack at front of compartment.



Above: ten channel installation, using reed radio equipment, showing elevator, trim and rudder servos abreast. Rudder servo in centre. Note trim bar, trim servo is at bottom of picture. Throttle servo abreast of relayless reed receiver. Aileron servo in wing of course.



Above: eight channel installation, showing three fuselage mounted servos. Elevator and throttle servos are at rear (right) with rudder servo immediately in front also coupled to steerable nosewheel. Receiver loosely packed in foam rubber.

BOAT SYSTEMS

CHAPTER 9

In the case of a model power boat the functional requirements for *complete* control can be given by four channels. Two channels are used for direct signalling of rudder, using 'bang-bang' operation with self-centring on release of signal; and two for motor speed control via a progressive servo. Simultaneous operation is not required, nor is this feature normally available on 4-channel equipment.

Since power boat operation is conducted at a slower rate, with slower response times and movement in only one plane to deal with, practical steering is also possible with 'progressive' action on the rudder servo, inching on the amount of rudder required, as judged by the response of the model, and thus operating as a 'pseudo proportional' system with conventional 'multi' equipment. This is, however, only practical with slow speed boats, and even then has definite limitations. For all fast power boats (i.e. those powered by diesel or glow motors), normal 'bang-bang' rudder control with self-centering on release of signal is essential, unless one is prepared to go to the expense of true proportional radio control.

The load on a boat rudder is appreciably greater than that on an aircraft control surface, calling for powerful servos in the case of high speed craft. However, rudder loads can readily be reduced by using a 'balanced' rudder—i.e. a rudder shape where a certain proportion of the rudder area comes in front of the pivot—see Fig. 55. For complete balance, and with a flat plate rudder section, the pivot point should be about one quarter to one fifth back from the leading edge so that some 20 to 25 per cent of the total rudder area comes in front of the pivot. In practice this should reduce rudder loads to a very low level with very little reduction in rudder efficiency. If the pivot point is located too far back, however, the rudder will be overbalanced which, whilst assisting the servo when moving to a displaced position will oppose the servo power when being returned to neutral again.

It is always desirable to use a balanced rudder on a high speed craft. An aircraft type servo is also desirable for short transit time so that rapid response can be produced following a signal. With slower speed craft transit time becomes less important and 'marine' servos are sometimes produced with high reduction gearing in order to obtain a higher output force at the expense of increased transit time.

Basically, therefore, as far as marine rudder control is concerned a *servo* is essential to obtain the necessary power for movement, and should preferably be operated by two channels for direct signalling. It is practical to use a single channel only for rudder control via a single-channel motorised actuator (not an escapement); and a second channel for motor speed and limit the radio equipment to two channels. This will not, however, give any advantage over straightforward single-channel operation for both controls will have to be operated in sequence by single-channel actuators. This can be done equally well with less expensive single-channel radio and a compound actuator (for rudder) and a secondary actuator (for sequence switching of engine speed).

With a high speed boat powered by a diesel or glow motor, direct signalling of rudder via two channels is essential; together with engine speed control via either one channel (giving sequence change-over from fast to slow) or two channels (normally progressive action). Four channel signalling is definitely to be preferred—Fig. 56.

Two channel operation of the engine throttle via a progressive servo enables a full speed range to be achieved from 'slow' to 'fast'. It is not, however, possible to arrange for 'stop' or 'reverse' with i/c engine power without going to the additional complication of a special gearbox with forward-neutral-reverse positions selected by mechanical movement, which movement would require an additional two channels and separate

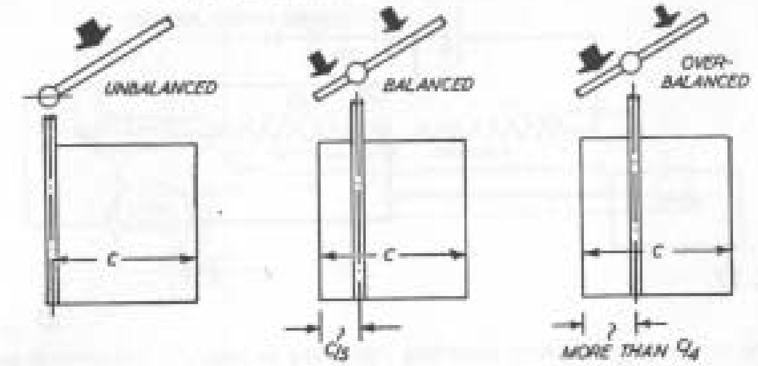
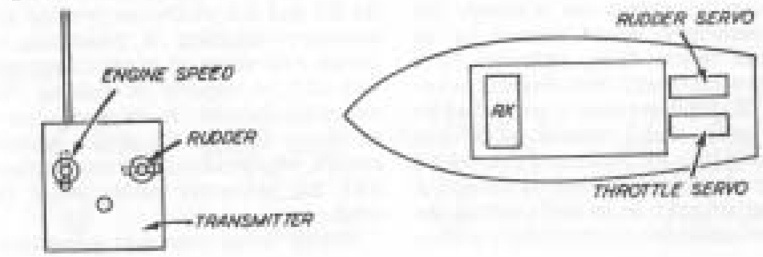


Fig. 55

Fig. 56



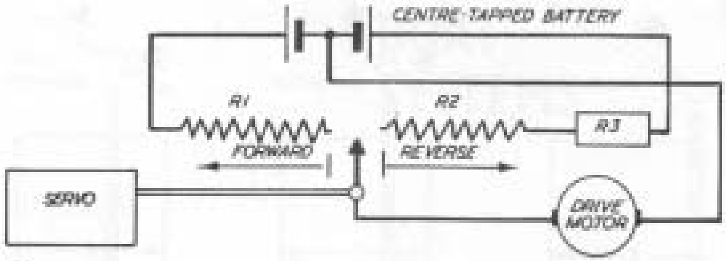


Fig. 57

servo to operate, if separate throttling action was still required via the normal engine throttle unit. The two actions could, however, be combined in a suitable gearbox unit so that the first 'inching' movement away from 'neutral' would engage gear and further movement progressively open the throttle with gear held engaged. Nothing like this—or even a basic gear-shift unit—has so far been produced commercially and so for most practical purposes R/C control of marine i/c engines is confined purely to engine speed control.

With electric motor power the possibilities for speed control are considerably enhanced. Again, however, few commercial control units have been produced and such devices are normally designed and made by the individual modeller. The requirements are basically straightforward in theory although the mechanical solutions may present a number of tricky problems to be worked out.

Fig. 57, for example, shows the basic requirements for a simple yet comprehensive speed control for an electric motor drive, operated by a progressive 'multi' (two channel) actuator. Wiper movement is controlled by the servo, which should be a slow running type for preference (i.e. with a longer transit time than is usual for model aircraft). In its mid position the wiper breaks the motor circuit, corresponding to 'stop'. If the servo is now inched in the 'forward' direction the motor circuit is completed through the wiper running onto the end of resistance wire R1. Further inching of the servo in the same direction progressively reduces the value of R1 in circuit until at the end of the travel, all the resistance is out and maximum current is being fed to the motor for 'full speed'.

To stop, the servo is inched back in the 'reverse' direction until the wiper runs off the end of R1 and the motor stops. At this instant the control signal is released to stop the servo in that position. For 'reverse' the servo is inched in the opposite direction, with the same progressive speed up of the motor as the wiper advances along R2. If necessary a further fixed resistance R3 can be connected in series with this circuit to reduce maximum current through the motor running in reverse.

The main practical difficulty involved is in arriving at a suitable form for R1 and R2 which can provide the necessary variation of resistance in circuit with slider or wiper movement and still be capable of passing the necessary current. A stepped system as shown in Fig. 58 would be one answer where individual fixed resistors with the necessary rating could be used.

Engine speed control is *essential* on

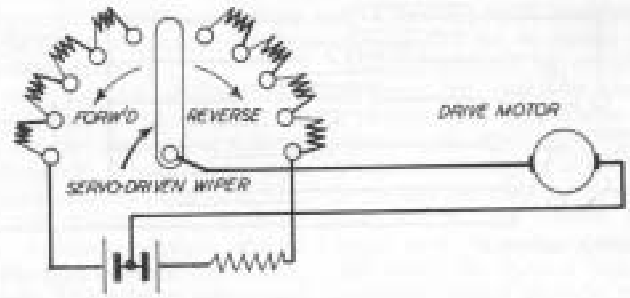


Fig. 58

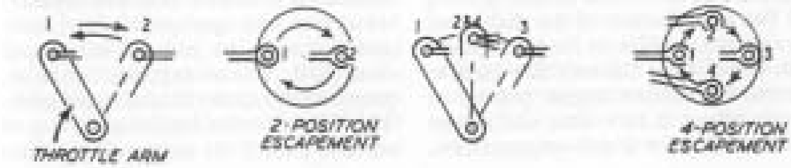
any high speed R/C boat (whether i/c engine powered or electric) and in such cases is best operated by two channels for direct selection. For slower running boats, however, speed of selection of any functional control is not a critical factor, although it is always desirable on rudder. This means that a 3-channel system can be perfectly adequate, the third channel for speed control operating through sequence switching.

In the case of a diesel or glow motor power unit this would mean using a single-channel actuator controlled by the third channel which would give either 'fast-slow-fast, etc.' in sequence; or 'fast-half-slow-half-fast, etc.', according to whether the actuator was a 2-position or 4-position type—see Fig. 59. The smaller diesel engines, in particular, do not always have a 'progressive' throttle response but basically only two speeds, fast or slow, in which case a 2-position actuator is all that is required. If the engine throttle does have a progressive response as regards actual engine speed, however, a 4-position actuator will provide an intermediate speed position, at the expense of increasing the number of individual positions in the sequence.

Sequence switching is also a suitable basis for operating any ancillary controls required, when any number of such controls can be operated via a single channel simply by 'stepping' through the required sequence. The basis of a sequence switcher is shown in Fig. 60. Receipt of a signal causes the switcher to step round to its next position and stop. The next control causes it to move on to the next position and stop, and so on.

Each 'stop' position is used to complete an external circuit connected to that particular contact. Since these external circuits are only used one at a time they can all share a common

Fig. 59



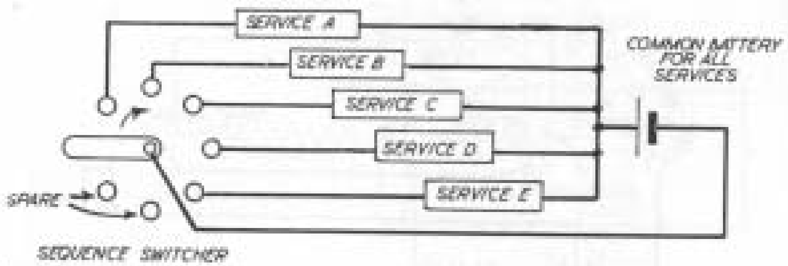


Fig. 60

battery, so that all the switcher really does is switch in the appropriate actuator at each position. To select any particular service, the operator has only to remember the sequence and work from the *last* control position. For example, with four sequence steps A, B, C and D, the sequence is A, B, C, D, A, B, C, D, etc. To step from A to B, or B to C or C to D will require one signal. To step from A to C, D to D, C to A, or D to B will require two signals (signal briefly blipped and then repeated); and so on. Five repeated signals will repeat the original signal.

A basic variation on this system is to adapt the switcher to be self-cancelling (i.e. return to a common neutral or 'off' position on release of signal) and need the signal to be held on to hold the switcher onto any particular contact. This can be applied to a dial type of control. The number of the particular control is selected on the dial which is rotated to a stop position and held there. The process of dialling the sequence number required sends out the necessary number of signal pulses to skip past intermediate positions, finally holding the last one. Return of the dial when the selected signal is no longer required then either steps the switcher back to neutral by further signal pulses, or merely allows it to release and return to neutral under a self-return action.

Certain single-channel actuators incorporate a form of sequence switching and may be used in similar fashion. Those that operate on a 'quick-blip' signal for a third service may not, however, always be easy to select by manipulation of a conventional multi-channel transmitter key. Also it is quite possible that with sequence signalling and switching a signal may be 'lost' in the process so that the actual sequence is lost. The greater the number of sequence steps involved on a single channel control, the greater the likelihood of this happening. If all the services are essentially ancillary, however, this presents no hazard at all to the safety of the craft. To get back to the correct sequence it is only necessary to try the next control signal, observe the response, and sort out the sequence from there.

Equally, whilst a single channel may control any number of sequence steps through a single sequence switcher, if additional channels are available it will be better to limit the scope of individual sequence switchers. Thus instead of controlling, say, eight separate services in sequence from one channel it would be better to separate these into two groups of four, each group having its own switcher and controlled by a separate channel, provided the extra channel is available. This also permits logical grouping of services and, if the radio side provides

for simultaneous operation, individual services in different groups can be operated simultaneously.

Note, however, that ancillary controls should never be allowed to encroach on the main or functional control demands. Thus rudder and engine speed controls must have first call on the number of available channels. Ancillary services should then be allocated between the *remaining* channels. The primary advantages of 'multi' operation are destroyed when any of the necessary functional controls are operated via a sequence system since this reduces them to the equivalent of single-channel working.

Installation of radio gear in a model power boat does not usually present any particular problem since there is usually plenty of space available. It is essential, however, to locate the receiver as far as possible from the main power unit—to minimise the risk of interference of an electric motor, and keep clear of oil if an i/c engine. Ideally, too, the receiver should be located in the dryest part of the hull.

Servos should be located as close as possible to the controls they operate to keep linkages down to a minimum and all wiring collected neatly together in the form of a cable which is then tied or otherwise fastened as high up inside the hull as possible. Main power leads between the battery and an electric drive motor should be located as far away from radio circuit wiring as possible and the motor suppressed against interference by means of a suitable capacitor connected across the brush terminals.

Vibration is not usually a problem, even with diesel powered boats, but laying the receiver inside a box lined with resilient material is still to be recommended. Servos, however, can be mounted directly to a suitable ply bulkhead or panel without special provision for shock absorption. The receiver unit can be further protected against dampness by enclosing in a polythene bag, sealed by binding with a rubber band around the emerging wires. This does, however, restrict access to the tuning control and it is important for maximum performance that the receiver should be finally tuned *with the receiver installed as it will finally be operated* (e.g. inside a polythene bag, if used for protection) *and with the boat in the water.*

Dampness is always a problem with model boat installations and particularly a salt atmosphere which can attack and corrode electrical contacts and cause rapid deterioration of electric motors. Plug-in wiring is to be preferred where servos and the receiver can be removed from the craft when not in use, so that these vital components can be stored under the best possible conditions in a dry place. Model boats, particularly larger craft, tend to be left in places that may not be all that dry, such as a garage.

If a permanent radio control installation is used, or necessary in a particular craft, care should be taken to dry off the boat as completely as possible after use and keep in a dry atmosphere. With i/c engined craft an efficient silencer system should always be used, coupled to an extension pipe which carries all oily exhaust waste overboard. Any fuel or oil spilt inside should be mopped up after running and the whole of the inside of the boat kept as clean as possible. Oil is also harmful on electrical contacts and is likely to ruin switches if it gets into them.

A particularly attractive but relatively undeveloped field of R/C application is to sailing yachts, and where multi-channel signalling is essential for proper control. Services required are (i) rudder, and (ii) altering sail settings, as necessary. The rudder

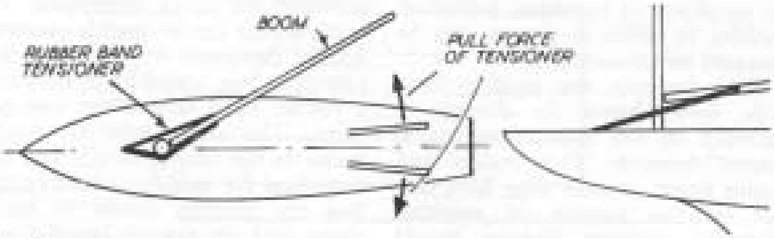


Fig. 61

operating requirements are virtually the same as for power boats and can be provided by a conventional multi servo mechanically linked to the rudder tiller arm in the usual way. There is, however, the question of whether normal 'bang-bang' action with self-centring, or 'progressive' action is best.

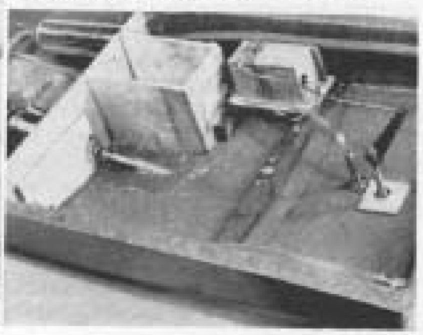
From a normal steering point of view the former is obviously best. However, the course followed by a sailing yacht is largely determined by the setting of its sails and any rudder offset needed to maintain on such a course is more in the nature of a 'trim' control. To apply constant 'trim' with a bang-bang control movement would require frequent blipping. With a progressive servo action the trim can be inched on or off, as necessary and left in the optimum position.

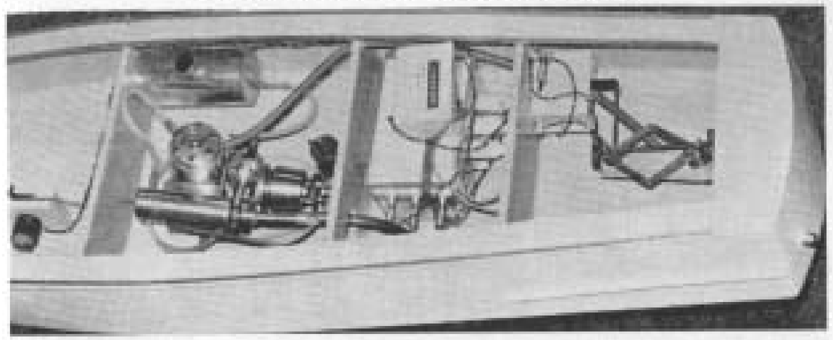
There are points in favour of both systems, whilst the balance and stability of the yacht will also have its effects. Since it is readily possible to provide either 'bang-bang' or pro-

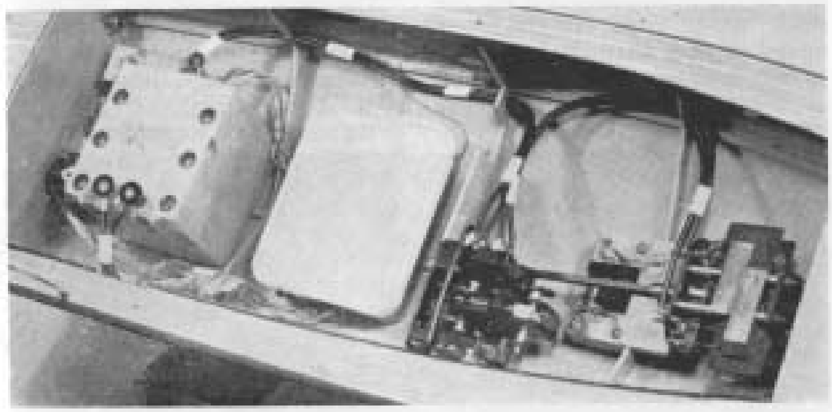
Left and below: multi installation in a glass fibre boat hull, showing installation of power unit with silencer. Receiver is mounted in plywood box, loosely supported in foam rubber. Right, top: boat installation showing power unit with silencer. Throttle servo is mounted ahead of motor, receiver in centre compartment and rudder servo at stern.

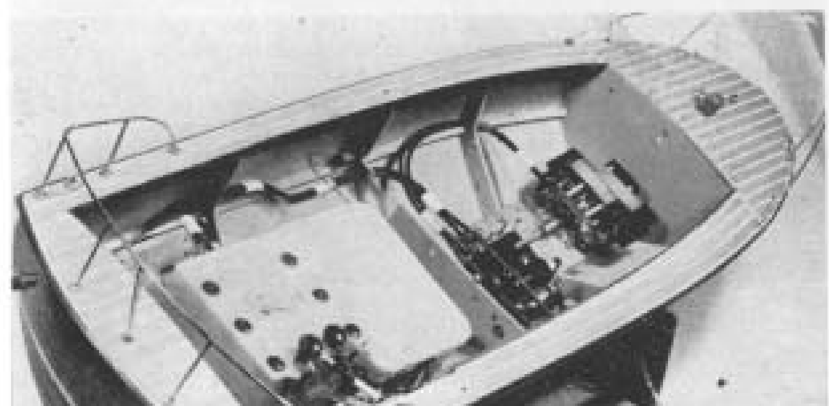
Right centre: radio and power unit installation in a high speed electric boat showing, left to right, re-chargeable power pack for main motor, receiver installation in waterproof box, throttle servo and power unit.

Right, bottom: another view of the same electric power boat, showing disposition of equipment in hull.









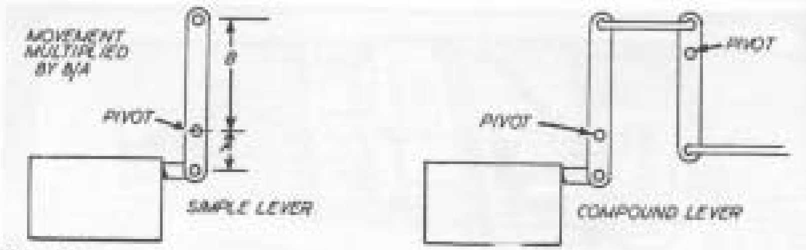


Fig. 62

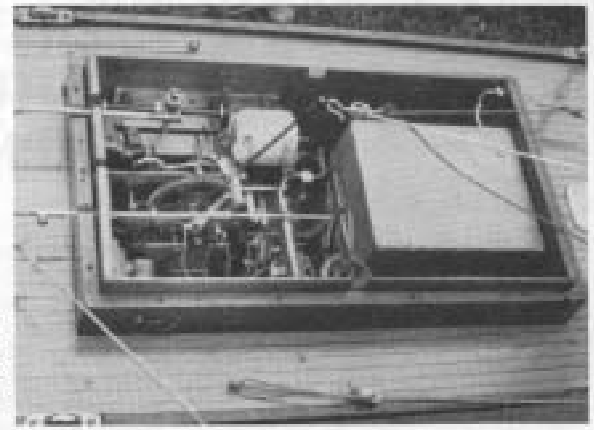
gressive action with a conventional 'multi' servo, it can be tried out with both modes of operation and the one which proves most effective as a control adopted. Alternatively, it could be arranged so that either method of operation could be selected by a switch which merely 'makes' or 'breaks' the two servo leads normally disconnected to change a 'bang-bang' action to 'progressive' (see Chapter 4).

As regards sheet handling (for controlling the setting of the mainsail and jib), the problems involved are almost purely mechanical. Sheet adjustment is best accomplished with a single servo adapted for 'progressive' operation and the necessary difference in movement required between the jib sheet and mainsail sheet accomplished either by a 'multiplying' pulley system on the main sheet, or differential levers, or a combination of both.

To prevent snagging on the main sheet it is necessary to bias the boom so that it is tending always to keep the sheet in tension. This can be accomplished by a single rubber band tensioning system, as shown in Fig. 61. Spring bias may or may not be necessary on the jib boom, depending on the length of run of the jib sheet and the methods of hauling in. Rigid push-pull or lever systems where the actual length of the sheets can be kept to a minimum are generally less liable to snagging than systems involving winding and unwinding the sheets around rotating drums (sheet winches).

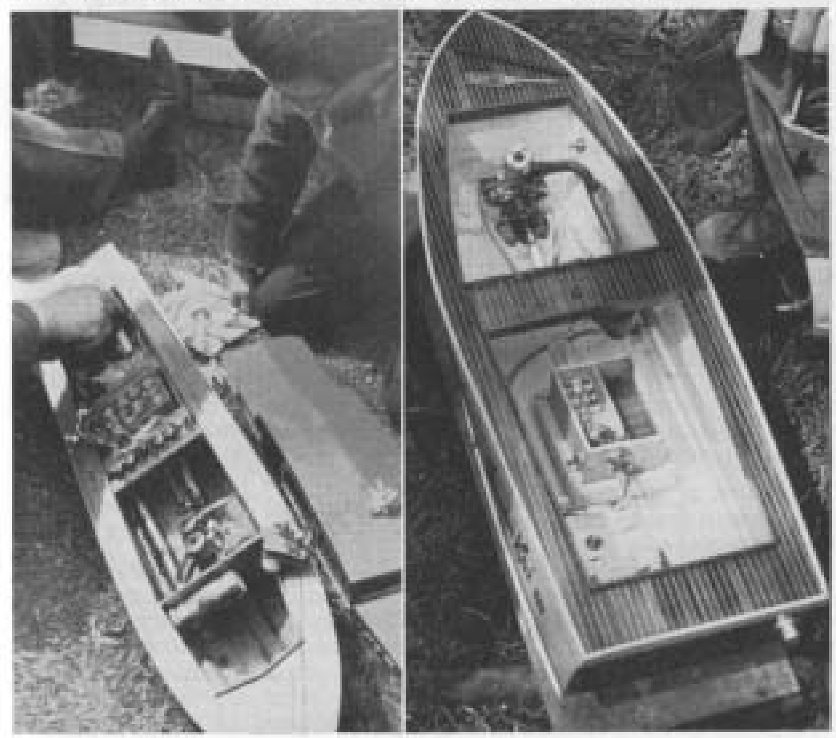
The basic requirements for comprehensive yacht controls are thus 4-channel signalling with two conventional 'multi' servos, the one servo operated 'bang-bang' or 'progressive' on the rudder, and the other wired for 'progressive' action for sheet hauling. There is no great advantage in arranging to haul the jib sheet separately (via a further two channels and another separate 'progressive' servo), although this does permit finer trimming. It also obviates the 'mechanical' problem of producing the optimum differential movement between the jib and mainsail linked to a common servo. Actual installation details are largely specific to the size and type of yacht. Space is not usually a problem since there is normally adequate room in the hull to accommodate a modern lightweight receiver, servos and the necessary batteries on a yacht as small as 24 in. l.o.a.

In general, however, the servo may need some modification in order to obtain the necessary movement for sheet hauling, aircraft-type servos normally having a push-pull movement of not more the $\frac{3}{8}$ in. each way about the neutral position. It may thus be necessary to connect the servo (mechanical) output to a lever system to obtain suitable multiplication of movement—see Fig. 62.



Multi channel installation in a radio controlled yacht, showing watertight radio installation box and servo mechanisms. Yacht enthusiasts must make their own servos, since none are available for this specialist purpose.

The old and the new in radio control boat installations. At left we see a Taplin Twin powered craft, displaying complicated "heavy duty" installation at the stern end. At right is an up-to-date example of R/C installation work, showing Grundig radio equipment in containing box. Motor in this case is a Cameron.10. Surprisingly, the transition from the type of installation on the left, to that on the right, took only three or four years.



OPERATION OF MULTI EQUIPMENT

CHAPTER 10

Certain commercial 'multi' transmitters and receivers are supplied pre-tuned and aligned and require no adjustment on the part of the user, nor may any means of adjustment be provided (other than opening the case and/or breaking manufacturer's seals which invalidate the guarantee). This applies particularly to tone filter equipment, although other designs of this type may provide a tuning control for optimum alignment of the receiver with regard to the transmitter used. With reed type receivers, matching transmitters invariably provide for audio tone adjustment, at least so that the individual transmitter 'tones' can be matched as accurately as possible to the reeds in the receiver. Again this may be pre-adjusted at the factory but would normally be checked by the user as a matter of course.

Basically, as far as a typical tone transmitter is concerned the frequency of transmission of a modern circuit is fixed by the value of the crystal employed. The only adjustment then normally available is a means of peaking the oscillator and RF output, together with a number of potentiometers, one for each tone or channel, which are adjusted separately to establish the required frequency of each AF tone. RF adjustment is merely concerned with producing maximum RF output and again would normally be factory pre-set. Certain transmitter designs may incorporate a meter measuring RF output or an indicator lamp (the brightness of which is a measure of the output signal strength) together with one or more trimmers—e.g. tuning slugs. These trimmers can be adjusted by a non-metallic screwdriver (necessary to avoid detuning) until maximum output is achieved, as shown by the meter or lamp. The job is purely a mechanical one of simple adjustment and instructions supplied with any given transmitter are specific on this subject. If RF output tuning is not detailed, then it can be assumed that the transmitter is already adjusted for maximum output and it is not intended that it should be further tampered with in this respect.

In all cases where RF tuning is attempted this should be done with a signal keyed on, or in the case of multi transmitters with simultaneous operation of one signal from *each* of the 'banks' keyed together. Lacking an indicator lamp or built-in meter, a

6 volt bulb connected temporarily between the centre tap on the aerial coil and the capacitor end of that coil will serve as an indicator. It is also useful to connect a milliammeter temporarily in one battery lead as an indication of current drain. RF output is adjusted by the coil core and observed by the brilliance of the indicator lamp. This point will normally be preceded by a fairly large rise in battery drain, as indicated on the milliammeter. Further adjustment may then produce little or no extra brilliance (or RF output) but materially increase the current drain by 'over-tuning'. This is not necessarily harmful, but does mean that the battery drain is higher than it need be.

The transmitter is now finally tuned as far as maximum range is concerned, and requires no further adjustment in this respect. It is now necessary:

(i) To tune the *receiver* to the transmitter.

(ii) To tune the *transmitter tones* to match the receiver reed bank.

The latter is a requirement of reed receivers only.

Since tone *frequency* is not affected by distance, but signal strength is, it is virtually necessary to carry out (ii) properly before finalising (i). However, to observe the necessary effect for (ii) the receiver must at least be roughly tuned to the transmitter to pick up the necessary signal. This usually represents no particular problem with a super-regen receiver on account of its broad tuning characteristics.

With the receiver and transmitter close by—say 2 or 3 ft. apart—remove or retract the transmitter aerial to avoid swamping the receiver with signal and switch on both transmitter and receiver. Make sure the receiver aerial wire is extended. Key any one tone on the transmitter when one of the reeds may or may not start to vibrate or 'drive'. Adjust the tuning slug on the receiver until a reed does drive, if necessary. Then adjust the tuning further in one direction until the reed stops driving and repeat by turning the tuning slug in the opposite direction until the reed stops driving again—i.e. determine the 'sweep' or number of turns of the tuning slug over which the reed continues to be driven. Optimum tuning is then obtained by finally adjusting the slug to mid-position of this 'sweep'.

This method is quite accurate enough for initial tuning. It does, however, depend on the transmitter tone keyed corresponding to the resonant frequency of one of the reeds. Thus if no reeds respond despite tuning adjustment, tried on

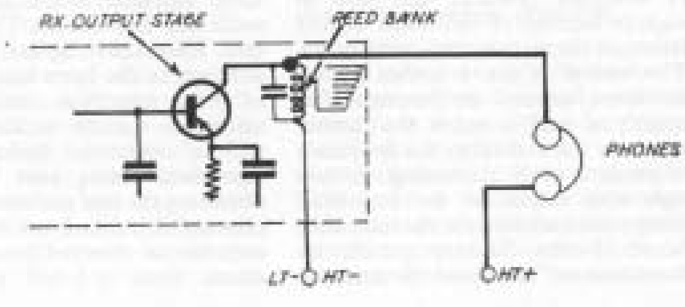


Fig. 63

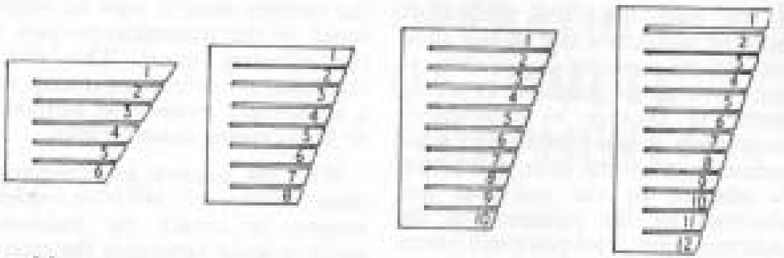


Fig. 64

all the tone keys, either one of the transmitter tone potentiometers must be adjusted (together with tuning) to try to pick up a reed to complete tuning, or phones used to listen in to the tone signal for tuning purposes. For this latter purpose phones can be connected across the output and HT plus, as shown in Fig. 63.

Having tuned the receiver to the transmitter at close range, the individual tones can be tuned accurately to the reeds, one at a time. Whilst the sweep of each transmitter tone circuit could cover the complete frequency range of the whole reed bank it is usual to restrict the adjustable frequency range on each potentiometer circuit to make for sharper tuning. Thus there is normally a definite allocation as regards which reeds *can* be tuned in via a specific transmitter tone key. Such allocations may vary with different transmitter-receiver combinations, although Fig. 64 is typical of standard or accepted practice, and also as regards location of individual control levers on the transmitter—see Fig. 12. The 'sweep' of pot. 1 is then limited to centre around the resonant frequency of reed 1, and at the extreme may not even overlap the frequency of reeds 2 or 3, depending on how tight the values of the individual components selected for the individual tuned circuits. Lacking specific information on 'allocation' the intended allocation of a particular potentiometer can be found by trial and error as that reed which is driven at or near the mid point of the pot. adjustment.

Tone tuning via the potentiometers is quite straightforward. An individual tone is signalled and the corresponding potentiometer adjusted to a position giving the strongest drive to that reed. Then check that this is repeated when the tone is 'blipped'. Adjustment which gives the strongest drive when the tone is held on continuously is not necessarily the best setting to ensure that good drive is picked up immediately when first signalled.

Special note: When adjusting the transmitter tone pots. to the receiver reeds, the servo battery should be disconnected (or the servo wiring to the reed bank disconnected). This is to ensure against the possibility of simultaneous operation of two adjacent reeds which could damage the related servo amplifier if connected to the reeds in a 'live' circuit. This applies to both relay and relayless installations, although in the latter case some types of servo amplifiers have a built-in safeguard against accidental simultaneous operation. Basically, in any case, reed tuning *must* be done by observing the *reed* performance (vibration and drive) and not the switching response as observed by servo movement.

Each tone is adjusted, in turn, until strong drive is obtained on all reeds from—and only from—their respective keyed signal. In the case of simultaneous transmitters after adjusting one tone, go to a tone in the other bank next and key *both* tones when adjusting the second. Repeat for the other tones, keying one from each bank simultaneously each time.

With restricted frequency adjustment normal on the tone circuits it is important that the transmitter component values for these circuits match the frequency range of the reed bank used in the receiver. If not, the transmitter tone tuned circuit component values may have to be changed before the combination will work. No multi-channel transmitter, therefore, will work a multi-channel receiver unless the tone values generated match those of the receiver reed bank.

Final tuning is then accomplished by a range check. Having got the individual tone circuits adjusted for maximum drive, the only thing which will affect the drive (apart from circuit instability) is a falling off in signal strength. If, therefore, transmitter and receiver are moved apart some considerable distance, further adjustment of *receiver* tuning can be made to establish the mid-position between the extremes (clockwise and anti-clockwise turning of the tuning slug) where reed drive is lost.

It is usual to carry out this range check when the receiver has been finally installed in the model, with servos and wiring connected, as installation can modify tuning slightly. A range check is carried out with the transmitter aerial fully extended. The greater the range, the smaller the tuning adjustment on the receiver between the two limits where tuning is lost, thus the more accurate the mid-position found is likely to be. In practice a range check at a maximum distance of about 200 to 300 yards is usually adequate, but some people prefer a longer distance check for safety.

Having established optimum tuning in this way—and nothing more elaborate than this technique is required—future 'range checks' can be made with the transmitter aerial retracted. First find the maximum operating range with the transmitter aerial removed, which may only be a matter of 10 yards or so, possibly less. If now a check is made *each time* before flying at a slightly less distance with transmitter aerial retracted and the receiver responds, it shows that normal range is being maintained (i.e. the receiver is still maintaining optimum tune). Any noticeable reduction in 'no aerial' range would, however, indicate that the receiver has gone off tune, and call for retuning at range with extended aerial.

In the case of superhet receivers, tuning cannot be accomplished satisfactorily by simple techniques. The only way of ensuring satisfactory alignment is by using proper test equipment, and commercial superhet receivers are normally factory pre-tuned and specified for return, or for sending to an approved servicing agent, should the need for retuning arise. The check on tuning, as far as the operator is concerned, is the standard long range and regular 'short range' check already described.

Superhet receiver operating frequency is determined by the frequency of the crystal in the local oscillator circuit and there is thus no 'signal tuning' as such but rather a matter of correct alignment of the various stages. This involves working with a very weak transmitter signal to avoid saturation and adjusting the mixer, IF stages and aerial coil in turn, each

adjustment having an inter-related effect. An oscilloscope is advisable to ensure that at no time during alignment does the signal reach full saturation as this can modify the tuning. Thus a weak signal will appear sinusiodal in form whilst saturation is indicated by a flattening of the peaks. IF tuning can be done with the receiver lid off, but peaking the RF tuning must be done with the lid on.

Tone adjustment with a superhet receiver is exactly the same as for the super-regen receiver previously described, except that the receiver should not be placed too close to the transmitter to avoid overloading and possible distortion of tones. A minimum distance of 10 ft. between the transmitter and receiver is usually required for distortion-free operation.

Once properly adjusted, the modern 'multi' transmitter-receiver combination is normally extremely reliable in operation and the principal causes of trouble are usually logical ones, such as run-down batteries. This applies to *all* the batteries in the complete system, which should have their voltage checked under load regularly and replaced (or recharged) as soon as necessary. The first thing to suspect in a case of non-working is the batteries. After that, look for the obvious such as broken connections or physical damage caused by a crash or shock. Actual circuit faults should be comparatively rare, and are usually difficult to trace on multi equipment without elaborate test gear and a thorough familiarity with radio control circuitry. Virtually all the faults with multi-channel radio equipment are dealt with on a 'return to manufacturer' (or service agent) basis, having first eliminated the possiblity of the more obvious—and common—causes of trouble mentioned.

Such periodic maintenance as is required—apart from regular battery checks—is largely confined to inspection of the reed bank for general condition, and inspection of the servos. Reeds should be inspected for oxidation or corrosion, all connections for soundness and contact cleanliness. Adjustment as initially set up (normally by the manufacturers or receiver manufacturers) should be permanent and require no further attention, unless the unit has suffered mechanical damage. In other words a reed bank should be left well alone, unless it is obvious that it does require adjustment. In this case a fair standard to adopt is:

(i) Reed comb clearance above the pole piece of the coil should be approximately $\frac{1}{32}$ in., with reeds static. If not, or individual reeds are out of line, adjust carefully by bending the whole at the base of the comb, or individual reeds.

(ii) Reed vibration should be about $\frac{1}{16}$ in. for reeds at the highest frequency end of the comb, increasing to about $\frac{3}{32}$ in. at the lowest frequency reed. The arc of vibration can be set by adjusting the individual contact screws.

(iii) Some slight interaction between adjacent reeds is tolerable —i.e. an adjacent reed trembles slightly, provided it does not close the contact on the unwanted channel. If interaction is too marked, this can be reduced by increasing the clearance (i) above.

(iv) If reed drive is poor, the clearance (i) may be too great. This is most likely to show up with simultaneous operation when the signal power is divided between two reeds.

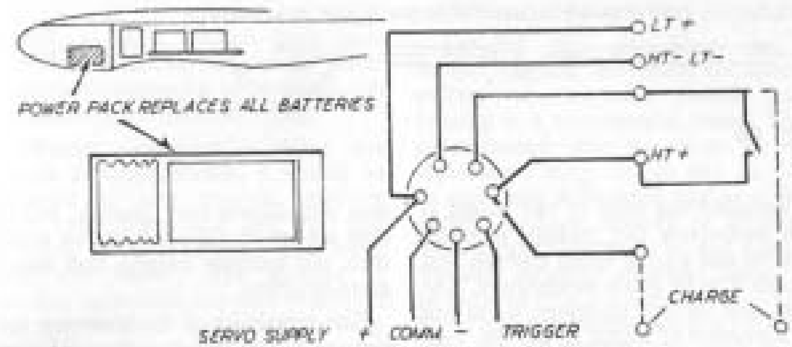


Fig. 65

As regards batteries for the receiver and servo circuits, DEACs (nickel-cadmium sealed accumulators) are now virtually the standard choice for all low voltage supplies—which means all the battery complement with all-transistor receivers. A single DEAC cell gives 1·2 volts and battery 'packs' can be made up by welding (or clamping together) a series of individual cells to give battery voltages of 2·4, 3·6, 4·8, 6·0 and 7·2 volts (these covering virtually all R/C requirements). The capacity of the DEAC cell is directly proportional to physical size. Standard sizes, together with typical applications and charging current data are given in Table I.

An alternative to DEAC batteries is the complete power pack which is, virtually, a compact transistorised circuit powered by a single DEAC battery of adequate capacity and with output tappings to provide the full and separate voltage complements required for the radio installation—see Fig. 65. The power pack can be permanently mounted in the model and recharged *in situ* between use. The power pack represents an advantage over separate DEAC batteries where a higher voltage is required (e.g. for the H/T supply on a valve/transistor receiver), but not as a general rule where only low voltage supplies are required.

The transmitter may be powered by dry batteries, DEACs or sealed lead-acid accumulators, or again a power pack designed to supply the specific voltages required. Size and weight of the transmitter is not usually critical, and so large dry batteries are probably the most economic solution for a valve transmitter requiring a high tension voltage order of 135 volts. All-transistor transmitters which normally operate on 6 to 18 volts, according to type, can most conveniently be powered by rechargeable batteries of either the DEAC or sealed lead-acid type, although again provision may be made to use dry batteries to reduce initial expense.

A brief description of aircraft trim must also be given as an essential feature of multi-channel R/C operation. Certain flight characteristics will be fixed by the aerodynamic design of the model, and its construction. Others will be variable by altering point of balance, rigging incidences, downthrust and sidethrust; and the control response will also be affected by the amount of movement of the various control surfaces.

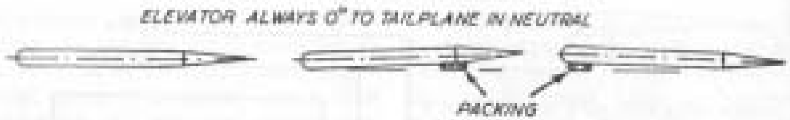


Fig. 66

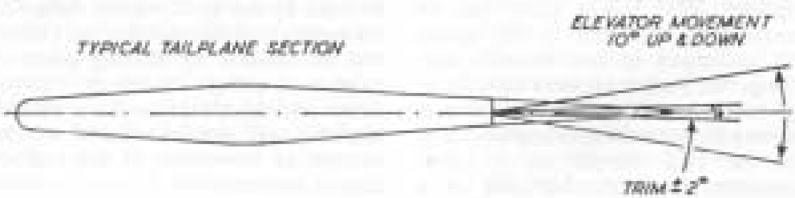
Provided the trim of the model is not excessively out, rudder, elevator, aileron and engine speed controls will enable it to be flown successfully. The first step should, therefore, be to put in a number of flights to get the 'feel' of the controls and at the same time observe any characteristics that need trimming out. Having got familiar with the handling of the model, final trimming can be made step by step. Note that this refers to permanent trim changes in the model line-up itself, just like trimming a free flight model, and not to any adjustment or use of trim controls operated by the radio channels.

The first requirement is that a 'multi' aircraft should fly *level* and *straight* with elevators neutral, and elevator trim neutral. *Level* flight can be trimmed out by altering the centre of gravity (e.g. by shifting the servo tray backwards or forwards) and/or altering the wing or tailplane incidence with packing to correct a diving or climbing tendency. *Straight* flight can be trimmed out by adjusting the sidethrust setting of the engine. Note that both these conditions could also be achieved by use of elevator trim and aileron trim *controls*, but if they are set up right initially by *model* trim, the controls become that much more effective.

The remainder of the trimming out process is then largely concerned with adjustment of control surface movements, Check first the full range of elevator trim movement. Full 'up' trim should correspond to a slight or moderate climb, no more, Full 'down' trim should correspond to level inverted flight; or if more advanced manoeuvres are to be attempted, such as inverted eights, a slight climb in the inverted position.

Aileron movement can then be adjusted, as necessary, to establish the optimum rate of roll. Too fast a roll (i.e. too much movement) may make it difficult to fly smooth ordinary turns. Too slow a roll may make the model lose too much height in rolling and need continual elevator correction. Differential movement can also be checked, according to the amount of yaw present. The fact that aileron movement may correspond to a specified (plan) figure does not necessarily mean that it is the optimum for a particular model as the rolling characteristics will be affected by model weight, as built. Models built from the same plan may, therefore, differ appreciably as regards optimum aileron movement for smoothest flying.

Fig. 67



Elevator movement is rather less critical although, ideally, it should be adjusted to give smooth, medium sized loops when held full 'up'; and inverted loops of similar size when held full 'down'. The amount of elevator movement required to achieve this may be quite small—e.g. typically about 8-10 degrees 'up' on a 6 ft. span aerobatic model and slightly more 'down'. This amount of 'up' may be insufficient to promote a true spin and it may be necessary to incorporate an override movement for this manoeuvre —see Chapter 7. Greater elevator movement than that required for smooth loops with the elevator held on will only mean that loops will have to be 'blipped' to control the diameter and will not be as smooth in consequence. This is a particular disadvantage for contest flying where established standards are high and smoothness of flying is very important.

Looping may also show up a further 'turning' tendency, the model pulling to one side rather than looping in a true vertical plane. This is commonly due to warps or an asymmetric wing. It can also be due to accidental differential rigging of the ailerons and can usually be adjusted by separate adjustment of one aileron attitude. Another common cause of an induced turn is a slightly out of line fin or rudder neutral position. Whilst this may be trimmed out with sidethrust at a particular flying speed it will show up as a turning tendency at other flying speeds. Obviously, therefore, the truer the model is built to start with, the easier it will be to trim out—and the better it will fly as a consequence. The fact that a radio model is 'correctable' in flight for building, rigging and trimming faults should not obscure the fact that where such faults exist they should be sorted out and eradicated. It will be vital to do this to achieve a top contest performance, anyway.

TABLE I. DEAC BATTERY DATA

DEAC 225 capacity: 0·25 amp./hr. charging current: 25 milliamps	Volts	1·2	2·4	3·6	4·8	6·0	7·2
	Size 1 in. dia. ×	0·36 in.	0·71 in.	1·1 in.	1·45 in.	1·8 in.	2·15 in.
	Weight (oz.)	0·5	1	1·5	2	2·5	3
DEAC 500 capacity: 0·5 amp./hr. charging current: 50 milliamps	Volts	1·2	2·4	3·6	4·8	6·0	7·2
	Size 1·33 in. dia. ×	0·39 in.	0·75 in.	1·15 in.	1·5 in.	1·9 in.	2·3 in.
	Weight (oz.)	1	2	3	4	5	6
DEAC 1000 capacity: 1 amp./hr. charging current: 100 milliamps	Volts		1·2	2·4	3·6	4·8	6·0
	Size 2 in. dia. ×		0·39 in.	0·75 in.	1·15 in.	1·5 in.	1·9 in.
	Weight (oz.)		2	4	6	8	10

Note: Size 225 DEAC is normally suitable for all aircraft applications (receiver and servo batteries) made up in the battery size required.

For heavier duty applications, particularly where high current drain is involved, size 500 can be used.

Size 1000 is particularly suited for heavy duty applications with high current drain where the additional weight can be tolerated (e.g. transmitters).

APPENDIX

Diagrams on following pages

F.A.I. AEROBATIC SCHEDULE

The pilot has 10 minutes in which to complete the programme of manoeuvres from the moment he receives the signal to start the engine.

5.4.1. *Take-off.* The model must stand still on the ground with the engine running without being held by the pilot of the mechanic and must take off into wind.

K = 5

5.4.2. *Double Stall Turns.* The model starts in level flight, noses up to the vertical attitude, yaws through 180°, then dives and makes one half of an inverted loop into vertical flight, then yaws through 180° again, finally recovering into upright level flight at the same height and on the same heading as the entry.

K = 15

5.4.3. *Combined Immelman and Inverted Immelman.* The model starts in level straight flight, pulls up into a half loop followed by half a roll, flies straight and level for approximately one second then makes half an outside loop followed by half a roll, recovering in straight level flight.

K = 10

5.4.4. *Loops.* The model starts the Loops manoeuvre flying straight and level, then pulls up into a smooth, round loop, followed by a second and third loop in exactly the same path with a straight and level recovery to finish.

K = 10

NOTE.—Loops must appear round and super-imposed to the ground-observer even in the presence of the wind.

5.4.5. *Inverted Loops.* The model commences the Inverted Loop flying straight and level, then noses down into Inverted Loops and recovers flying straight and level on the same heading and altitude as the entry.

K = 10

5.4.6. *Rolls.* Model starts from straight and level flight then rolls at a uniform rate through three complete rotations and finishes in straight level flight all on the original heading, the time of the three rolls to be approximately 4 seconds.

K = 10

5.4.6. *Slow Roll.* Model commences from straight and level flight then rolls slowly at a uniform rate through one complete rotation the approximate time of the roll to be 5 seconds.

K = 10

5.4.7. *Rolling Circle.* Model commences in level flight, makes half a roll into inverted circular flight, subsequently making a further half-roll at each quadrant of the circle so that the model flies alternately upright and inverted in consecutive quadrants. The model recovers in straight level flight on the same heading and at the same height as the entry.

K = 15

5.4.8. *Tail Slide.* The Tail Slide commences with straight and level flight, pulls up to a vertical position, slides downward tail first for two plane-lengths, recovers in a right-side-up position and finishes in straight and level flight at the same altitude as the entry.

K = 15

5.4.9. *Horizontal Eight.* The plane commences flying straight and level, pulls up into $\frac{3}{4}$ of an inside loop, does one full inverted loop starting from straight down, then $\frac{1}{4}$ of an inside loop finishing in straight and level flight.

K = 8

5.4.10. *Cuban Eight.* The plane commences flying straight and level, pulls up into an inside loop and continues until heading downward at 45°, does half roll followed by another inside loop to 45°, does half roll followed by straight and level recovery at same altitude of entry.

K = 6

5.4.11. *Vertical Eight.* The plane commences the Vertical Eight flying straight and level, pulls up into one complete inside loop, follows with one inverted loop and recovers straight and level at the same altitude of entry.

K = 10

5.4.12. *Inverted Straight Flight.* The model starts level and upright, makes a half roll to inverted, flies straight and level inverted for a minimum of 5 seconds and recovers with a half roll to the upright position.

K = 8

5.4.13. *Inverted Eight.* The plane commences the Inverted Eight flying straight and level inverted, turns left one complete circle, turns right one complete circle, flies straight and

level in the same direction as the entry still inverted.

K = 15

5.4.14. *Top Hat.* Model starts in straight level flight, pulls up into a vertical climb and makes a half roll, then levels out inverted on same heading as entry. After short inverted flight model dives vertically, performs a half roll and finally recovers in straight level flight on same heading and height as entry.

K = 15

5.4.15. *Spins.* The plane establishes a heading direction by flying straight and level, pulls up into a stall and commences the spin through one, two, three turns and recovers to level flight on the same heading as the initial flight direction.

K = 8

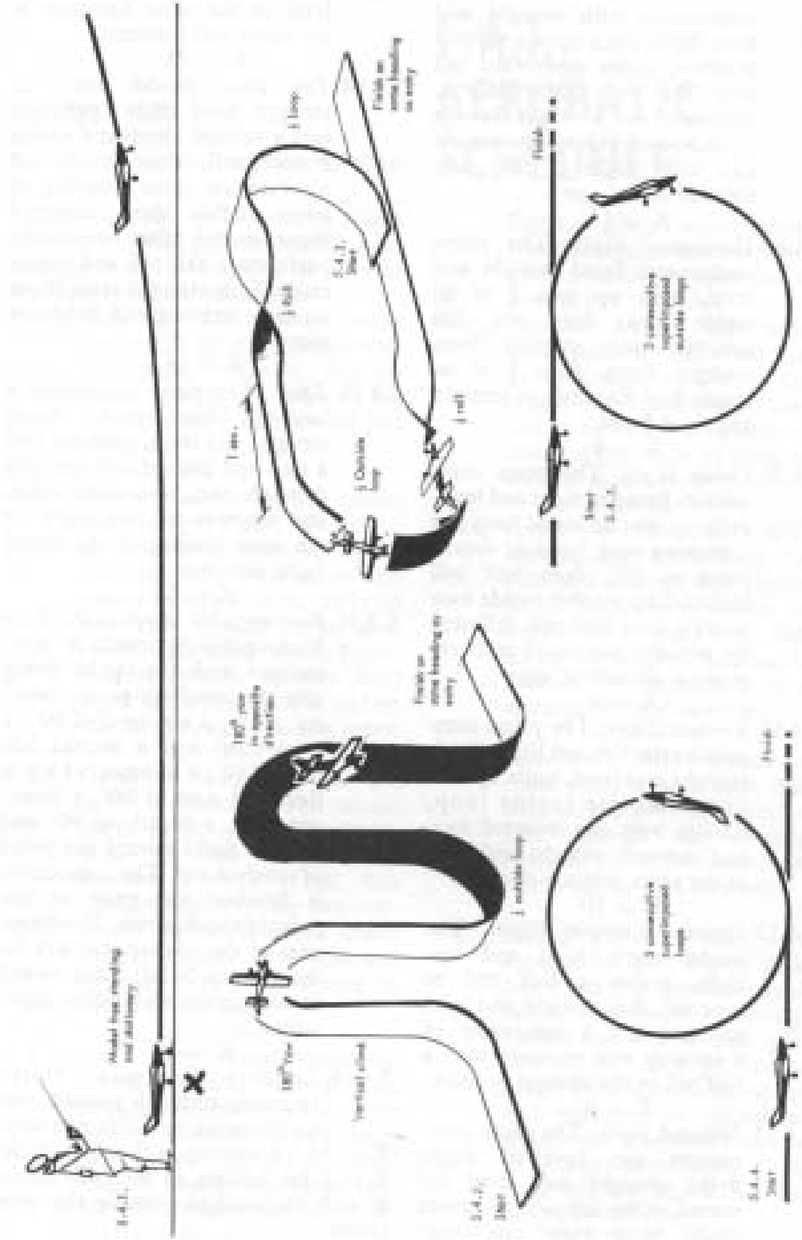
5.4.16. *Rectangular Approach.* The Rectangular Approach is commenced with the model flying into the wind above the landing circle, a left turn of 90°, a cross-wind leg, a second left turn of 90°, a down-wind leg, a third left turn of 90°, a cross-wind leg, a fourth of 90° and straight flight toward the point of touch-down. The manoeuvre is finished just prior to the point of touch-down. The direction of the manoeuvre will be determined before each round in accordance with safety regulations.

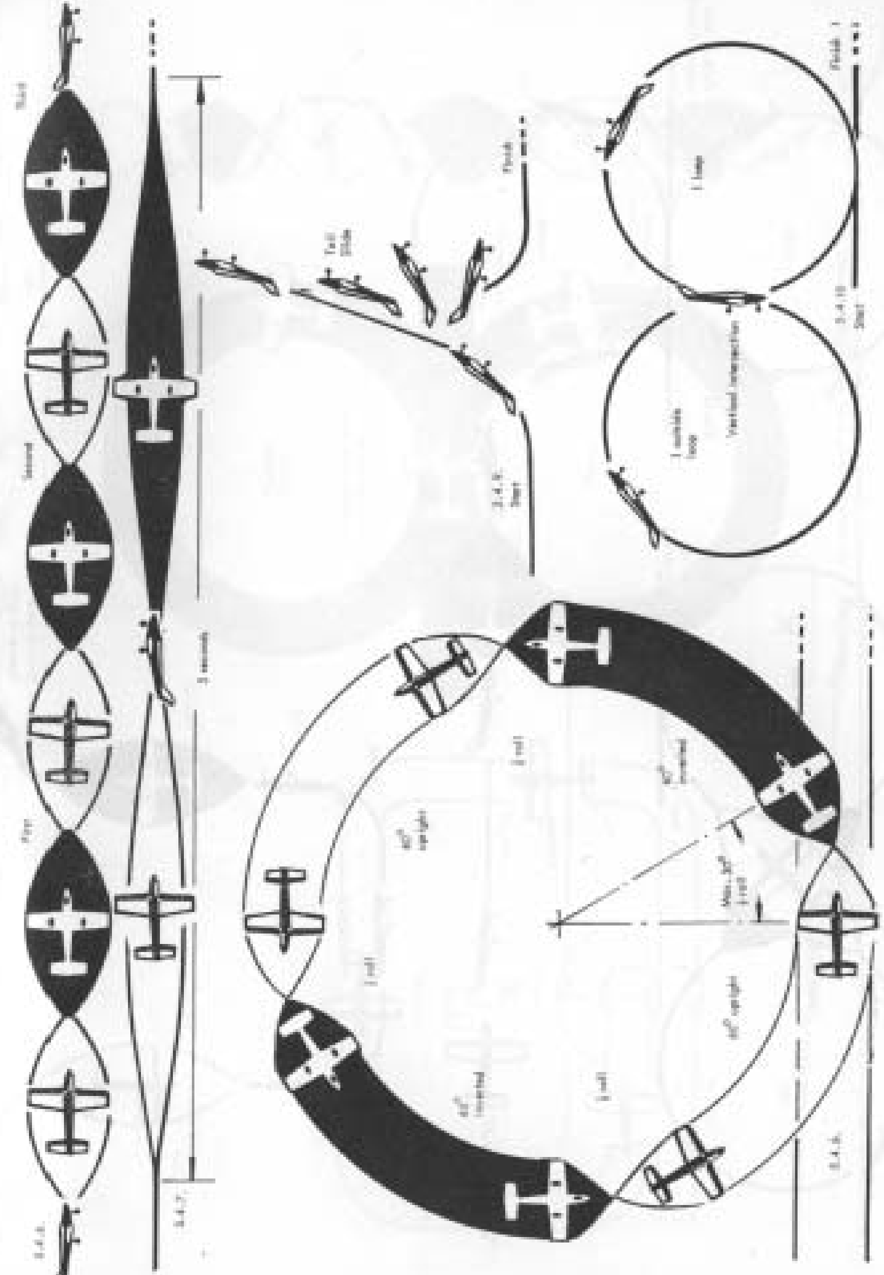
K = 10

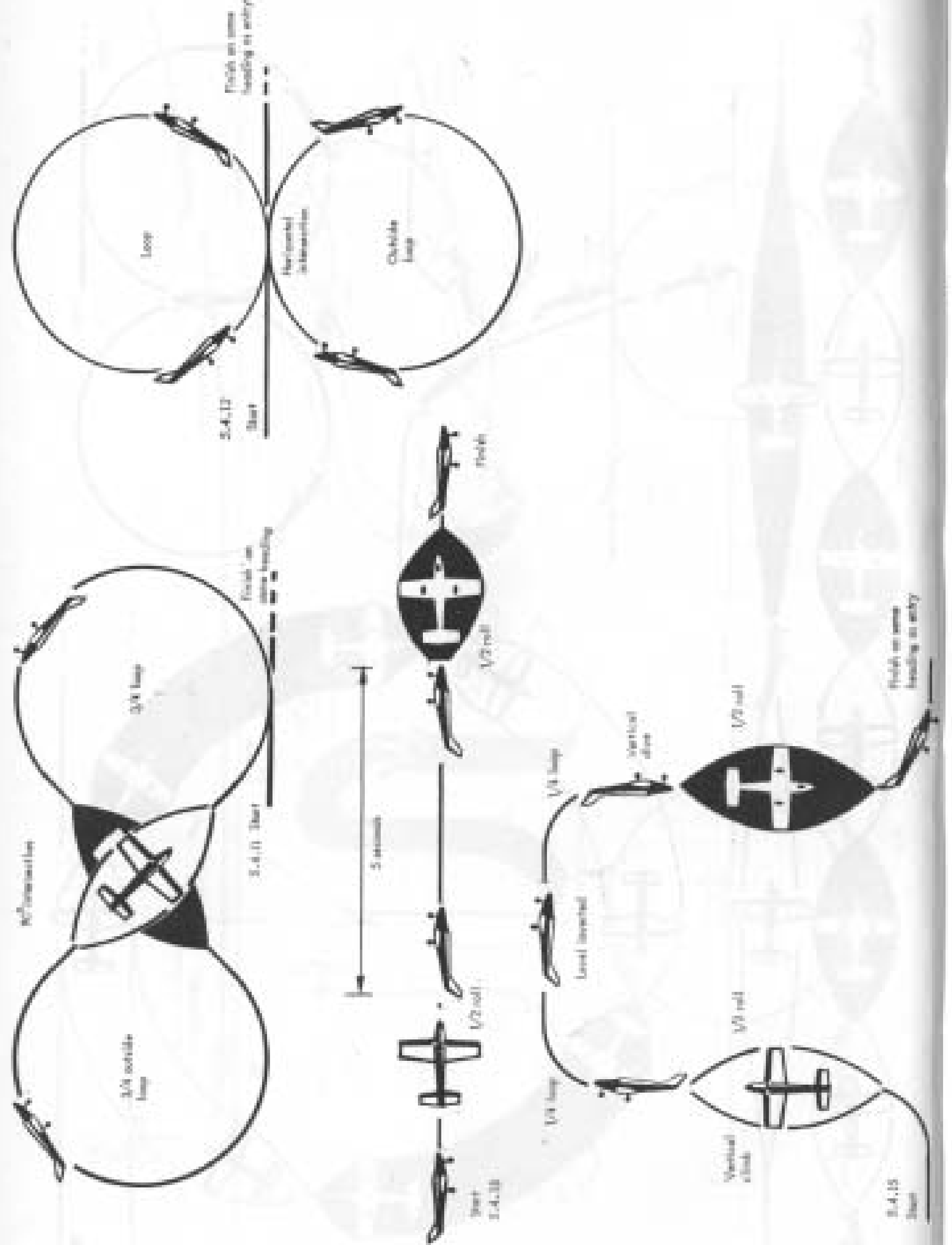
5.4.18. *Landing.* The model flares smoothly to touch ground with no bouncing and rolls to a stop.

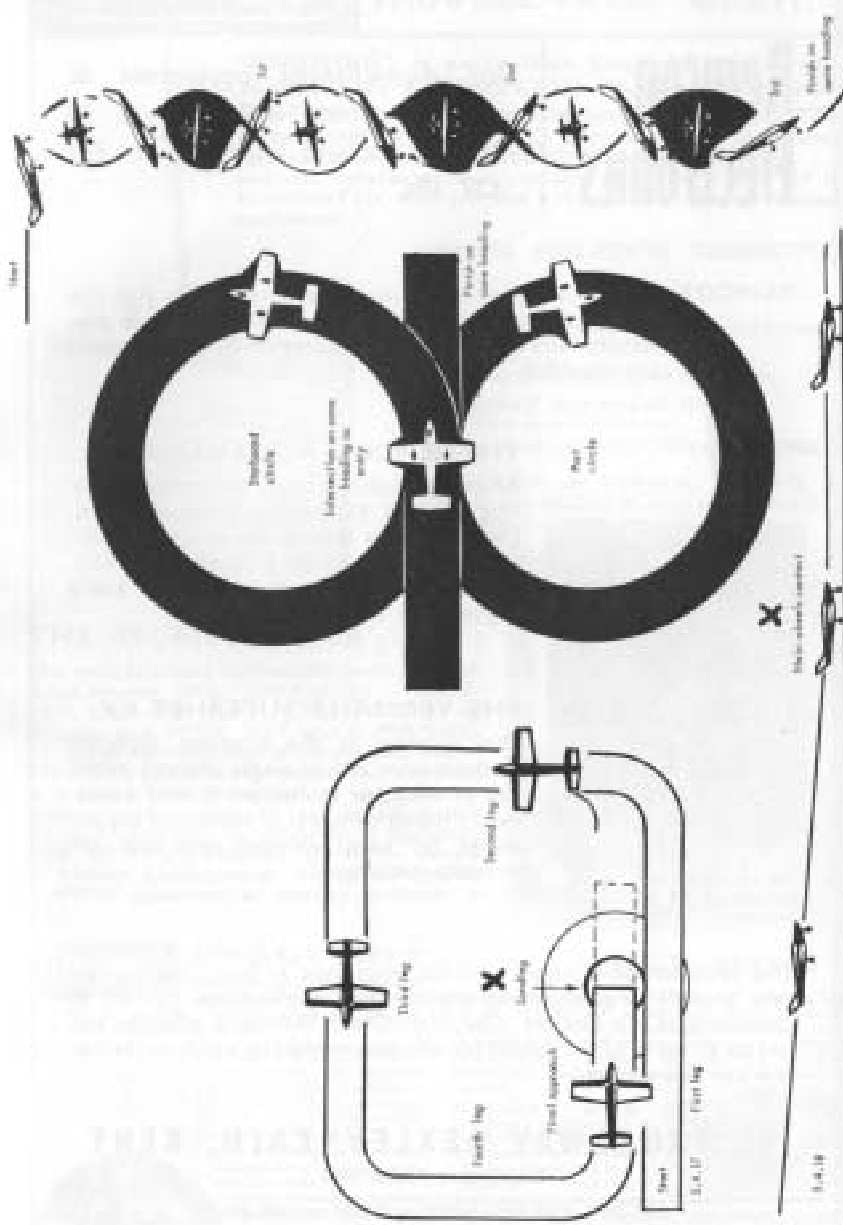
K = 10 for landing in the 25m circle.
K = 5 for landing in the 50m circle.
K = 0 for landing outside the 50m circle.

Total maximum points 2,000.









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	TYPE 'T'	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	TYPE 'P'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
500	TYPE 'I'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	TYPE 'T'	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	TYPE 'P'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1,000	TYPE 'T'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	TYPE 'P'	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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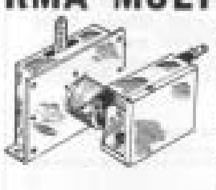

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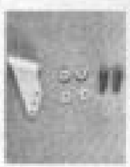

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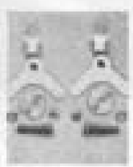
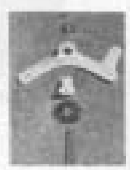


Nylon aileron bellcrank assy. complete 9/6 Metal aileron horn, etc. 7/6



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